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THE VIABILITY OF TRANSPLANTED BONE

AN EXPERIMENTAL STUDY*

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AND

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It is well known that when a piece of bone is excised and then buried in the tissues of an animal, new bone formation takes place in the transplant. Whether the transplant itself survives and proliferates or whether its presence merely acts as a stimulus to the surrounding tissue and a framework for the new bone is a disputed question with some evidence to support each hypothesis.

Formerly, the "metablastic" theory of bone formation prevailed; that is, the theory that various members of the connective tissue group possessed the power under certain circumstances or conditions of environment of changing from one to another. This theory has been generally displaced by the "neoblastic" theory which predicates a definite bone-forming cell, the osteoblast. According to this theory, the osteoblasts are formed either in the general developmental process through differentiation from indifferent mesenchymal cells, from osteoblasts which are present (periosteum and endosteum) through regenerative processes or through differentiation of mesenchymal tissue cells which have remained undifferentiated. Therefore, the mesenchymal tissue cells that have remained undifferentiated may develop into osteogenic tissue, bone cartilage, adipose tissue, connective tissue, fascia, tendons or muscle. Such cells may be aroused from their latent stage in later life by traumatic, infective or toxic irritation or by metabolic disturbances, and heterotropic bone formation may be thus explained. The inorganic salts are of importance only when they come in contact with osteoblasts or remaining undifferentiated mesenchymal cells. If this contact is not obtained, osteogenesis does not take place in the soft tissues and the calcium salts are of secondary importance.

Dead bone, elements of bony tissue and synthetically prepared salts of bone are used in bone formation through the activity of the osteo-

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* From the Laboratory of Experimental Surgery, Department of Surgery, School of Medicine of Leland Stanford Junior University.

blasts. Some authors, Ollier, Orth, Gruber, Baschkerzew and Petrow,¹ Memilon, Nageotte, Regard, Bancroft, Weiderarick, Simon, Terrarini and others advocate that at the same time these materials should stimulate the nonspecific connective tissue by a metaplasia into bony tissue. Barth, Morpurgo, Martin, Pockhammer, Baschkerzew and Petrow and Rohde transplanted bone ash into the soft parts. Barth alone found bone formation in the abdominal cavity after putting bone ash intraperitoneally into a cat. After transplanting boiled bone into the soft tissues, Haas,² Ely,³ Sultan, Axhausen, Baschkerzew and Petrow and Regard never found bone formation.

Rohde concluded from his experiments that "bone building power is found only in specific bone building tissues—osteoblasts of the periosteum and marrow endosteum. Metaplastic bone building from the usual connective tissue of the musculature, muscle septa, tendons, fascia, and the subcutaneous tissue does not take place."

Haas² is one of the most staunch believers in the survival of the transplant and in its inherent, active, independent regenerative powers. He found that bone, when transplanted into a muscular bed and thereby removed from any possible influence of other osseous tissue, shows definite signs of cellular activity. He concluded that "even though there is an initial destruction of the greater part of a transplanted bone, sufficient amount of osteoblastic tissue survives in the region on the periosteum, endosteum, and about the Haversian canals to regenerate new bone. . . . There is sufficient energy stored in the osteoblastic cells of a live bone transplant placed in a muscle and removed from all osseous contact to form a union between two fragments of a fracture in such a transplant." He found that repair in these transplants,

1. Baschkerzew, N. J., and Petrow, N. N.: Beitrage zur frein Knochenueberpflanzung, Deutsche Ztschr. f. Chir. **113**:490, 1912.

2. Haas, S. L.: Spontaneous Healing Inherent in Transplanted Bone, *J. Bone & Joint Surg.* **4**:209, 1922; Transplantation of Bone into Joints, *Arch. Surg.* **13**:426 (Sept.) 1926; Regeneration of Bone from Periosteum, *Proc. Soc. Exper. Biol. & Med.* **10**:57, 1912; The Experimental Transplantation of the Epiphysis, *J. A. M. A.* **65**:1965 (Dec. 4) 1915; The Importance of the Periosteum and the Endosteum in the Repair of Transplanted Bone, *Arch. Surg.* **8**:535 (March) 1924; A Study of the Vitality of Bone after Removal from the Body, *ibid.* **7**:213 (July) 1923; Further Observation on the Survival of Bone after Removal from the Body, *ibid.* **1**:196 (Jan.) 1925; Free Transplantation of Bone into the Phalanges, *J. A. M. A.* **62**:1147 (April 11) 1914; Fractures in Transplanted Bones, *Surg. Gynec. Obst.* **36**:749 (June) 1923; Function in Relation to Transplantation of Bone, *Arch. Surg.* **3**:425 (Sept.) 1921; Transplantation of the Articular End of Bone Including the Epiphyseal Cartilage Line, *Surg. Gynec. Obst.* **23**:301 (Sept.) 1916.

3. Ely, L. W., and Cowan, J. F.: A Study of Buried Bone, *J. Orthop. Surg.* **1**:100 (Feb.) 1919; Bone Growth in Transplanted Bone, *Arch. Surg.* **9**:215 (July) 1924; An Experimental Study of Buried Bone, *Ann. Surg.* **70**:747 (Dec.) 1919.

as in the repair of normal bone, is effected by the formation of cartilaginous callus which later becomes ossified. This response takes place even though the bone is removed from the normal functional stimulation, but on account of the lack of functional demand it undergoes degeneration and is gradually absorbed.

Lewis⁴ expressed the belief that cortical bone transplants remain alive and retain their vitality and proliferative powers.

Phemister⁵ found that a fracture through a transplant unites by callus formed from the surviving cells of the transplant in the vicinity of the fracture. Concerning its ultimate fate, he said:

The subsequent changes which a transplant undergoes depend upon its composition and location. According to Roux's law of functional adaptation a transplant placed in a useful location, that is, a bony defect, undergoes progressive changes, while one in a useless location undergoes chiefly retrogressive changes and is gradually removed. . . . Transplanted into a bony defect, substitution of the dead cortex gradually occurs by the ingrowth of capillaries with dilatation of the Haversian and Volkman's canals, absorption of old bone and deposition of new bone in its place.

Murphy and Barth are among those who expressed belief that osteogenesis does not occur from any part of a transplant.

Ely³ stated the opinion that "both the bone and the marrow in the buried fragments die. The marrow is then reformed by blood vessels pushing in from the surrounding tissues, and a certain amount of new bone is laid down upon the old, especially along the margins of the dead trabeculae. All grafts probably die and are efficient only as new bone is built upon the old by new blood vessels pushing into them from the receiving bones."

Janeway⁶ said:

There is a death of the implanted bone, a revascularization and penetration by granulation tissue and through this means the production of new Haversian canals . . . and the deposition of new bone in concentric layers about the newly formed blood vessels. These changes are solely dependent upon the living and regenerative powers of the transplanted periosteum and marrow.

If bone could be grown away from the other tissues of the body, the method by which new bone is formed and the question of life or death of the transplant might be definitely solved. Attempts to grow bone in vitro have not been successful. In the following experiments, an attempt was made to grow bone in the soft tissues of the animal by

4. Lewis, E. J.: *Experimental Work on Bone Transplantation*, Surg. Gynec. Obst. **18**:572, 1914.

5. Phemister, D. B.: *The Fate of Transplanted Bone and Regenerative Power of Its Various Constituents*, Surg. Gynec. Obst. **19**:303, 1914.

6. Janeway: *Ann. Surg.* **52**:217, 1910.

enclosing transplants in a membrane that would prevent the passage of cells but still permit the dialysis of nourishment necessary for living tissues.

The possibility of a vegetable membrane fulfilling these requirements was considered, and after a number of different vegetables were examined, the membrane from the inner surface of an onion leaf was found most satisfactory. These membranes were removed from the inner concave surfaces of the middle layers of the onion. They were thin and transparent and dialyzed salt and sugar, but not peptone solution or the proteins of horse serum.

A review of the literature showed that collodion membranes have been used for biologic purposes. After some experimentation, membranes made according to the following formula were found best suited for our purpose:

	Cc. or Gm.
Ether	10
Absolute alcohol	30
Ethyl acetate	5
Collodion (Parlodion brand)	3.5

Forms were made but cutting off test tubes about 2 inches from the closed end. The solution was poured into the tube, drained, and dried in air for one minute, after which the membranes were removed in water and placed in 95 per cent alcohol for several days. All membranes were autoclaved in salt solution before being used. Membranes made by this method were fairly strong, moderately thick and flexible and were found to dialyze salt, proteoses, tyrosine, dextrose and water but would not dialyze the proteins of horse serum.

In the following three groups of experiments, segments of ribs, fractured longitudinally, were transplanted to the muscles of the back, knee joint and abdominal cavity: first, living fractured segments were transplanted for controls; second, the transplants were killed by boiling; third, the fractured living transplants were enclosed in an onion or collodion membrane in an effort to prevent the ingrowth of cells and blood vessels from the tissues of the animal and at the same time to permit the dialysis of nourishment necessary for the life processes in the bone itself.

TECHNIC

The animals used were dogs. With the animals under ether anesthesia, a segment of rib about 2 inches (5 cm.) long was removed, the deep periosteum being left intact. The segment of rib was then divided into three pieces. Each piece was fractured longitudinally and the fragments placed in apposition and tied with silk suture material. These pieces were kept in warm saline solution until transplanted.

In group 2, when onion membrane was used, the transplants were simply wrapped in the membrane. In group 3, when the transplants were enclosed in collodion, the mouths of the sacs were tied with silk and sealed with collodion. Under aseptic technic, the pieces of rib were transplanted to the muscles of the back, the knee joint and the abdominal cavity. The animals were killed at intervals of from eight to forty-two days, and the bone examined microscopically.

PROTOCOLS

DOG 1.—*Large, healthy male. Duration of experiment, twenty-one days.*

Procedure.—A segment of rib was removed as already described, divided into three pieces and each of these fractured longitudinally. The fragments were then placed in apposition and tied with silk suture material. One piece was then inserted into a muscle of the back, one into the abdominal cavity and one into the cavity of the right knee joint.

The dorsal, rib and abdominal wounds healed by first intention. The skin of the incision into the knee joint remained apart, but the deeper structures were apparently healed until three days before the experiment was terminated. At this time the animal began to favor the injured leg, and a profuse watery discharge appeared.

The animal was killed with illuminating gas twenty-one days after the operation.

Necropsy.—The dorsal wound had healed normally, and the bone was enveloped by muscular tissue.

The abdominal wound was perfectly healed. The piece of bone was found embedded in omental tissue close to the abdominal scar and enclosed in a thin fibrous capsule.

There was a small, oval, granulating wound on the lateral surface of the right knee at the site of the original incision. When the joint was opened, a bloody synovial fluid escaped. The piece of bone was found immediately beneath the surface wound, embedded in coagulum and tissue.

Microscopic Examination.—The bone in the dorsal transplant (figs. 1 and 2) was within the muscle and surrounded by fibrous tissue. Many osteoclasts occupied depressions in the sides and ends of the bone. The multinuclear giant cells were also found within the bone in the haversian canals and along the bone spicules. There was also marked osteoblastic activity along some of the spicules, haversian canals and periphery of the bone. In some areas the osteoblasts were arranged in layers and gradually approached the characteristic appearance of fibroblasts and fibrous tissue. The marrow was well vascularized and in most places quite fibrous, although areas of lymphoid and fatty marrow still remained. Most of the lacunae contained nuclei. Near one end of the transplant, above and separated from the cortical bone, was apparently an area of callus formation containing bone, cartilage and fibrous tissue. The fracture line did not show in the sections cut.

Most of the lacunae in the abdominal transplant were empty, and the cortical bone was apparently dead. The marrow was well vascularized and for the most part quite fibrous, although an area of lymphoid marrow was present in one end. Osteoclasts were present about the spicules in the marrow cavity, especially in the region where the fibrous and lymphoid areas join. Here, again, there was a gradual transformation of osteoblasts into fibroblasts, and active osteogenesis was present.

Few, if any, dark staining nuclei were found in the lacunae of the articular transplant. The cortical bone was apparently dead. There was some osteoclastic

activity about the ends of the bone; osteoblasts were not seen. Some fibrous tissue was found growing into the marrow cavity (figs. 1 and 2).

Dog 2.—Large male. Duration of experiment, twenty-one days.

Procedure.—A segment of rib was removed as before, boiled for five minutes, divided into three pieces and each piece fractured longitudinally. One piece was embedded into a muscle of the back, one in the abdominal cavity and one in the cavity of the right knee. All wounds healed readily.

Necropsy.—The transplant in the back was removed from the sacrospinalis muscle. The fragments were in good apposition.

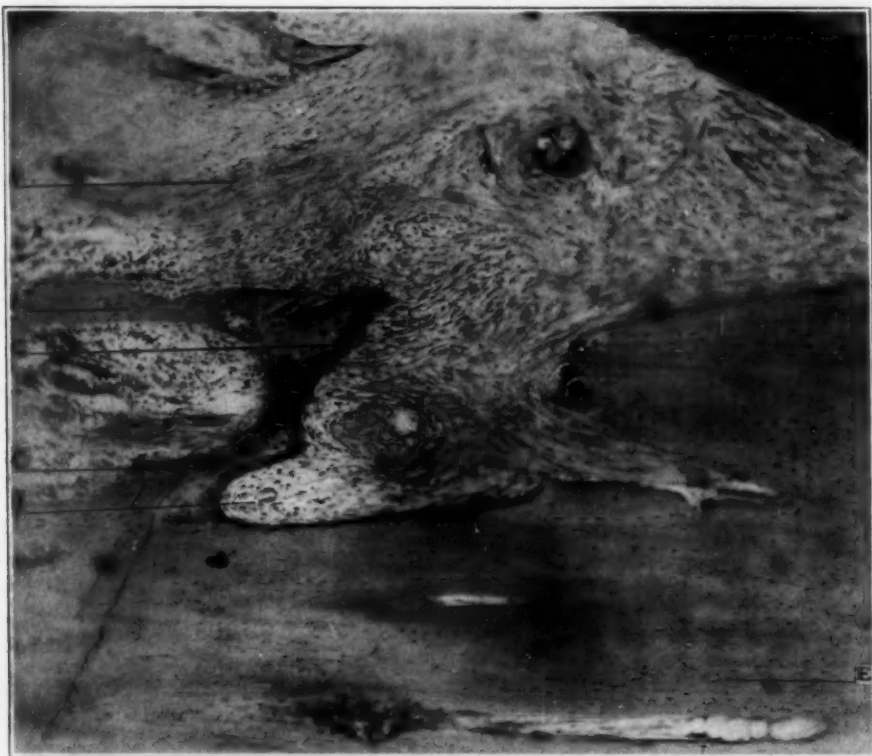


Fig. 1 (dog 1).—Section of dorsal transplant. *A*, fibrous tissue; *B*, dark staining lacunae of the bone; *C*, osteoblasts; *D*, blood vessel; *E*, empty lacunae in cortical bone. Leitz, oculars, 2; objective, 2/3; bellows length, 18 inches.

The transplant in the abdomen was found embedded in the mesentery about 10 cm. from the incision. The fragments were in good apposition.

One fragment was found embedded in the fibrous tissue of the medial side of the joint capsule of the knee. The original incision was on the lateral surface. The other fragment was found free in the joint cavity.

Microscopic Examination.—The dorsal transplant was found surrounded by fibrous and muscle tissue. The periphery of the cortical bone showed signs of absorption. Fibrous tissue had grown into the haversian canals and between the

fragments. The lacunae of the cortical bone were empty; neither osteoblasts nor osteoclasts were seen. Blood vessels containing many red blood cells were present in the marrow cavity.

A longitudinal section of the abdominal transplant showed it to be surrounded by fibrous and fatty tissues. There were scalloped areas at the end of the bone, but no osteoclasts were distinguishable. The haversian canals appeared enlarged and contained some fibrous tissue. A few capillaries containing red blood cells were seen. The bone appeared to be disintegrating around the haversian canals, and the lacunae were empty.

In the transverse section, the transplant was surrounded by fibrous and fatty tissue with fibrous tissue between the fragments and in the haversian canals. The

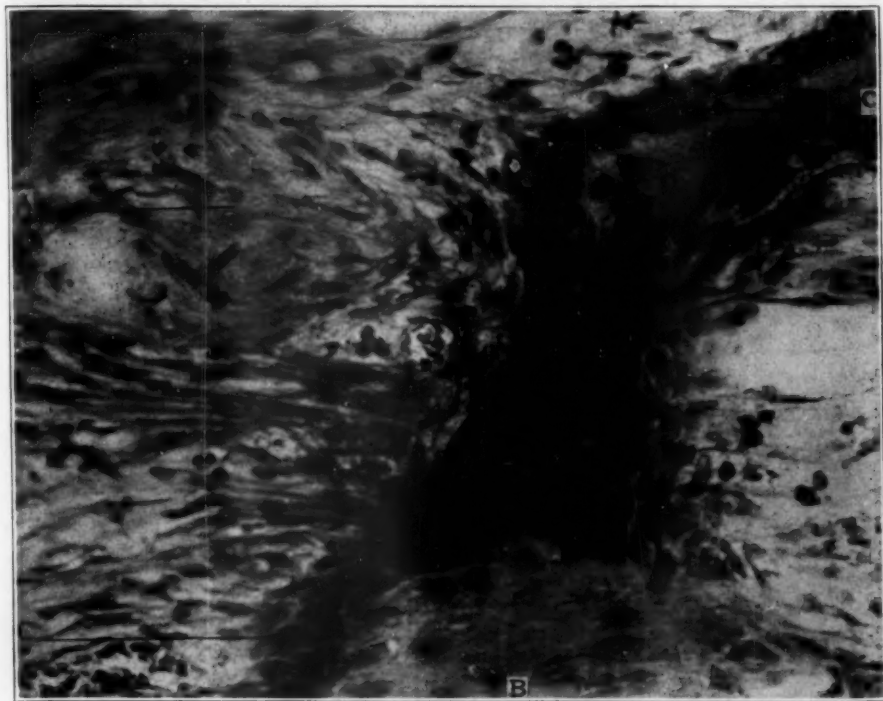


Fig. 2 (dog 1).—Same section shown in figure 1, more highly magnified at C-C. A, fibrous tissue; B, nuclei in newly formed bone; C, osteoblasts. Leitz, oculars, 2; objective, 2/3; bellows, full length.

periphery of the cortical bone showed signs of irregular absorption. Blood vessels containing red blood cells were seen in the fibrous tissue. The bone immediately surrounding the haversian canals stained lighter than other cortical bone. Most of the lacunae were empty. Some of the haversian canals contained necrotic marrow.

A longitudinal section of the articular transplant showed little fibrous tissue on the outside of the transplant. The haversian canals appeared to be somewhat enlarged. In some areas the lacunae of the cortical bone were empty, and in others there were contained nuclei. Neither osteoclasts nor osteoblasts were seen.

DOG 3.—*Large white male. Duration of experiment, twenty-one days.*

Procedure.—One and one-half inches (3.7 cm.) of rib was removed, most of the deep periosteum being left in place. The bone was divided in three pieces and each piece fractured longitudinally. The fragments were placed in apposition and tied with silk suture. Each of the three pieces of bone were then folded in an onion membrane. One was buried in the sacrospinalis muscle, and the other two were placed in the abdominal cavity. The wounds healed by primary union.

Necropsy.—In the back, the transplant was found at the site of incision. The fragments were freely movable.

In the abdomen, both transplants were found embedded in a mass of omentum directly below and adherent to the abdominal wall.

Microscopic Examination.—The fragments of the dorsal transplant were widely separated and embedded in fibrous and muscle tissue. In only a few places could the onion membrane be distinguished. The lacunae of the bone were empty. The edges of the cortical bone were irregular, eroded and scalloped. Osteoblasts or osteoclasts could not be definitely defined. Fibrous tissue had grown to the edge of the bone and into the haversian canals. Blood vessels were present in many places in the fibrous tissues.

The two abdominal transplants were surrounded by a continuous wall of onion membrane. Outside of this membrane was fibrous and fatty tissue which was vascular. Inside the membrane were the two fragments, some apparently dead striated muscle, one silk suture and several collagen fibrils. Signs of healing were not seen at the fracture line. The marrow was apparently dead. The lacunae of the bone were empty. The edges of the cortical bone were irregularly eroded and showed some scalloping of the borders. Neither osteoblasts nor osteoclasts were seen.

DOG 4.—*Large healthy male. Duration of experiment, eleven days.*

Procedure.—A segment of rib was removed as before, divided into three pieces and each piece fractured longitudinally. The fragments were then placed in apposition, tied with silk suture material and transplanted as follows: one piece into the muscles of the back, one piece into the abdominal cavity and the third into the knee joint of the right hind leg. All wounds healed normally, but the animal became sick and was killed eleven days after the operation.

Necropsy.—The animal was extremely emaciated. All wounds healed by first intention.

The piece of bone transplanted to the back was found embedded in healthy striated muscle, closely surrounded by fibrous tissue.

The abdominal transplant was found buried in the omental tissue about 2 cm. above the incision.

The transplant in the knee was found embedded in the tendon of the rectus femoris.

Microscopic Examination.—The marrow of the dorsal transplant was fibrous and quite vascular. Except for an occasional lacunae near the ends and sides of the bone which contained nuclei, the lacunae were empty and the bone apparently dead. There was some absorption along the sides and end of the cortical bone, but no osteoclasts were observed. The fracture line did not extend across the section, but there was no evidence of osteoblastic action.

The marrow cavity of the abdominal transplant contained a small amount of lymphoid tissue and serum. There were some fibrous proliferation and extension of capillaries into one end of the bone. The lacunae were empty. Neither osteo-

blasts nor osteoclasts were present. The bone was apparently dead, and there had not been any proliferation, although some absorption had occurred along the cortical bone.

The transplant from the knee did not show any sign of growth or regeneration, and the bone was apparently dead. The marrow was largely replaced by fibrous tissue; the lacunae were empty, and the cortical bone showed considerable erosion. Neither osteoblasts nor osteoclasts were present.

Dog 5.—*Large Airedale, male. Duration of experiment, forty-two days.*

Procedure.—A segment of rib was removed as before, divided into four pieces, and each piece fractured longitudinally. The fragments were placed in apposition

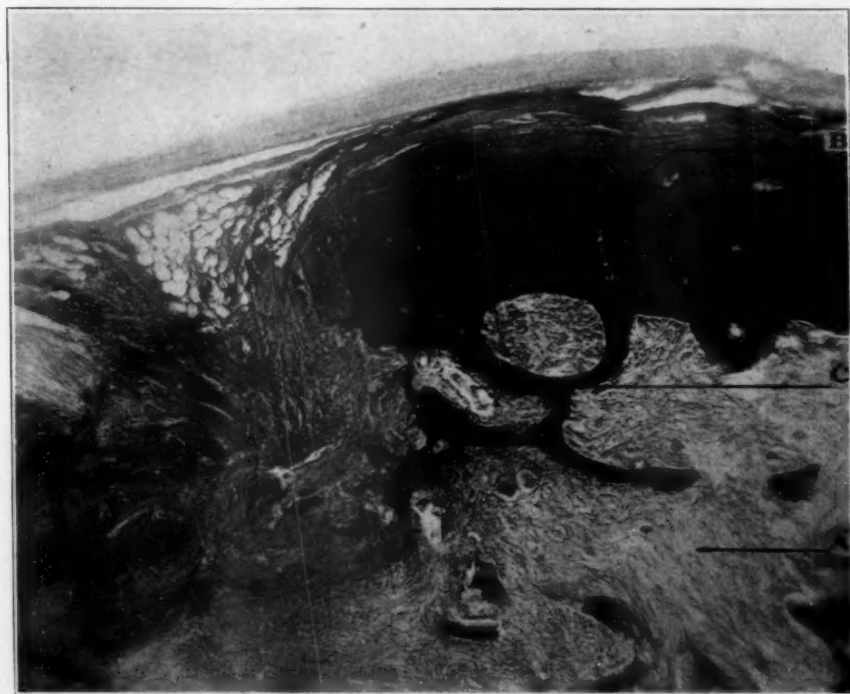


Fig. 3 (dog 5).—Section of unenclosed dorsal transplant. *A*, fibrous tissue in marrow cavity; *B*, irregular absorption along edge of bone; *C*, blood vessels. Leitz, oculars, 2; objective, 2/3; bellows, 20 inches.

and tied with silk suture material, and two of these were placed in flexible collodion sacs. In each case, the sac also contained a small amount of physiologic solution of sodium chloride, and the open end was tied with silk. One piece of rib enclosed in the collodion membrane and one unenclosed segment were buried in the sacrospinalis muscle. Of the other two pieces, one was enclosed in a collodion sac and one placed free in the abdominal cavity.

Two weeks after the operation, a small, fluctuant tumor developed beneath the skin just below the dorsal scar. This was aspirated, and about 10 cc. of blood-tinged serum obtained.

Necropsy.—All wounds were perfectly healed.

One large piece of muscle containing the two transplants was excised from the back.

Both abdominal transplants were found embedded in the mesentery.

Microscopic Examination.—Sections of the unenclosed dorsal transplant are shown in figures 3 and 5. Several fragments of bone were found encapsulated by fibrous tissue and embedded in the muscle. Both the cortical and the medullary portion of the original transplant of bone had been broken into several pieces and all fragments showed erosion with formation of many small crescent-shaped cavities. The lacunae were empty, and the bone was apparently dead. Osteoblasts



Fig. 4 (dog 5).—Section of dorsal transplant enclosed in colloidal membrane. *A*, space occupied by membrane; *B*, irregular end of bone with irregular absorption and many osteoclasts (*F*); *C*, fibrous tissue; *D*, osteoblasts; *E*, empty lacunae in cortical bone. Leitz, oculars, 2; objective, 2/3; bellows, 13 inches.

were seen in places (fig. 5). There was an occasional foreign body giant cell and a few large multinuclear cells about the periphery of the bone.

A section from the enclosed transplant from the back is shown in figure 4. The membrane dissolved while the sections were being prepared and was represented by an unbroken clear space surrounding the transplant. At the top of the sac there were many thin, irregular folds of fibrous tissue which apparently followed the folds, creases and irregularities of the collodion sac where it was bent and creased by the silk tie. The open spaces between these thin strips of fibrous tissue were occupied by serum, leukocytes and foreign body giant cells. Little

fibrous tissue was found between the membrane and the muscle, but a fairly dense fibrous capsule enclosed the bone within the membrane. Although a break in the membrane was not obvious from the microscopic examination, such an opening must have occurred, since a blood vessel containing some red blood cells was found in one haversian canal. The bone itself showed some signs of absorption and no evidence of growth. The lacunae were practically all empty, and the bone was apparently dead. The marrow was replaced by fibrous tissue. In places about the edges of the bone, large multinuclear giant cells, apparently osteoclasts, occupied small depressions of Howship's lacunae.

The abdominal transplant not enclosed in collodion membrane was found surrounded by a narrow band of fibrous tissue. The marrow was largely fibrous



Fig. 5 (dog 5).—Section of unenclosed dorsal transplant. *A*, fibrous tissue; *B*, bone; *C*, osteoblasts. Leitz, oculars, 4; objective, 2/3; bellows, full length.

but in some places was fatty in character. Both the cortical and the cancellous part of the bone showed marked evidence of absorption, and many isolated spicules of bone were seen. The lacunae, with a few possible exceptions around the periphery, were empty. About the margins of the bone multinuclear giant cells, apparently osteoclasts, occupied depressions in the cortex and haversian canals. A few osteoblasts were seen. There was some slight evidence of regeneration in a few peripheral areas, but on the whole the bone appeared dead.

The abdominal transplant enclosed in the collodion membrane was surrounded by a capsule of fibrous tissue. The membrane which dissolved during fixation and staining was represented in most places by a thin, clear line. The membrane evidently did not remain intact, since the marrow was well vascularized and several blood vessels were seen. The marrow was composed of fatty and fibrous tissue.

The bone showed marked evidence of absorption and, except for an occasional small area about a peripheral spicule, the lacunae were empty and the greater portion of the bone appeared dead. About some of these peripheral living spicules were osteoblasts and some new bone. In several places, osteoclasts occupied depressions in the bone.

Although the evidence of regeneration was not extensive, it appeared quite definite in certain of the marginal areas.

Dog 6.—Medium sized female. Duration of experiment, thirty-nine days.

Procedure.—Two inches (5 cm.) of rib was removed from the right side. The periosteum was so adherent that it was removed entirely. This segment was boiled for six minutes and then divided into three portions, each of which was fractured longitudinally. The fragments were placed in apposition and tied. Each piece was then wrapped in an onion membrane and one buried in the sacrospinalis muscles and the other two transplanted in the abdominal cavity.

Two days after operation, the dog developed enteritis from which it died thirty-seven days later. A small, fluctuating swelling developed beneath the dorsal scar, and 1 cc. of serous fluid was aspirated.

Necropsy.—The animal was greatly emaciated. All wounds healed by primary union.

In the back, the muscle under the dorsal wound was atrophied. The transplant, still surrounded by portions of the onion membrane, was found loose in the center of an abscess.

The abdominal transplants were adherent to the mesentery and greater omentum. The bowel showed a diffuse enteritis and was filled with blood.

Microscopic Examination.—In the dorsal transplant, a small piece of cortical bone was surrounded by a membrane which in turn was encapsulated by fibrous tissue (fig. 6). Along one side were many spicules of bone, near which were seen a few darkly staining bodies which were apparently homogeneous and in which nuclei could not be demonstrated. The cortical bone showed evidences of absorption. The edges were regular, except for the side on which the spicules were found. The lacunae were empty. Neither blood vessels, red blood cells, fibrous tissue, osteoblasts nor osteoclasts were seen inside the membrane (fig. 6).

Transverse section of the abdominal transplant showed a round section of bone with the fracture near one side. The edges of the cortical bone were straight. Neither osteoclasts nor osteoblasts were seen. The bone was surrounded by a membrane inside of which neither fibrous tissue, blood vessels nor red blood cells were seen. In a longitudinal section of the transplants, the membrane was not continuous. Blood vessels, fibrous tissue or red blood cells were not seen inside of the bone. The cortical bone showed some irregular absorption, and the lacunae were all empty. Neither osteoblasts nor osteoclasts were seen.

In both the transverse and longitudinal sections, the marrow cavity was filled with pale staining and apparently dead cells.

Dog 7.—Medium sized female. Duration of experiment, thirty-eight days.

Procedure.—Two inches of rib was removed from the right side, the deep periosteum being left intact. This section of rib was divided into four pieces, and two of the pieces were boiled for six minutes. Each piece was fractured longitudinally and the fragments approximated and tied. Each piece was then tied in a collodion membrane and an unboiled and a boiled piece in their membranes were embedded in the muscles of the back, and the other boiled and unboiled pieces were placed in the abdominal cavity. The animal developed distemper during convalescence.

Necropsy.—The transplants from the back were found embedded in muscle tissue.

Both abdominal transplants were found in the mesentery at the site of the incision where the mesentery was adherent to the parietal peritoneum.

Microscopic Examination.—There was no apparent difference between the two transplants recovered from the muscles of the back. The edges of the bone were eroded, and many osteoclasts were seen. A great deal of fibrous tissue was found around the bone and immediately adjacent to it. In this fibrous tissue were many blood vessels. All the lacunae were empty. Signs of regeneration or new growth were not found. Osteoblasts were not seen (figs. 7 and 8).

In one section of the abdominal transplants, the position of the membrane could be demonstrated. Inside the membrane was fibrous tissue (greater in



Fig. 6 (dog 6).—Section of dorsal transplant enclosed in onion membrane. *A*, continuous onion membrane; *B*, necrotic bone marrow; *C*, irregular end of cortical bone; *D*, large dark staining bodies without demonstrable nuclei which may be bone fragments or possibly osteoclasts; *E*, empty lacunae of cortical bone. Leitz, oculars, 2; objective, 2/3, bellows, 16½ inches.

amount at one end), blood vessels and red blood cells. Near the middle portion, the marrow was lymphoid and fatty. The lacunae were empty, and there were no signs of new growth. A great deal of erosion was present and some osteoclasts were seen. No osteoblasts were distinguished. The other section from the abdomen was apparently replaced by fibrous tissue. On gross examination it had the appearance of bone, but serial sections showed only dense connective tissue in this peculiar arrangement.

Dog 8.—*Small female. Duration of experiment, eight days.*

Procedure.—About 2 inches of rib was resected and divided into four pieces. Each piece was fractured longitudinally and the fragments placed in apposition and tied with silk suture material.

Two of these pieces, one enclosed in a collodion membrane and one unenclosed, were buried in the sacrospinalis muscle. Two other pieces, one enclosed in a collodion membrane and one unenclosed, were placed in the abdominal cavity.

This dog had previously been used for producing experimental abscess of the liver, and after operation the animal became progressively weak and emaciated.



Fig. 7 (dog 7).—Section of dorsal transplant boiled and enclosed in colloidal membrane. *A*, membrane; *B*, fibrous tissue outside membrane; *C*, fibrous tissue inside membrane; *D*, fibrous tissue growing through membrane; *E*, irregular edge of cortical bone; *F*, empty lacunae of cortical bone. Leitz, oculars, 2; objective, 2/3; bellows, 14 inches.

An abscess developed in the sacrospinalis muscle at the site of implantation. The dog was practically dead when the experiment was terminated eight days after operation.

Necropsy.—The animal was extremely emaciated. All the wounds healed normally.

In the back, the transplant enclosed in the collodion sac was found in a subcutaneous abscess directly below the dorsal wound. The unenclosed transplant was found adherent to the muscle tissue.

One transplant in the abdomen was found adherent to the intestine and parietal peritoneum. The other segment was adherent to the greater omentum.

Microscopic Examination.—The transplant from the back enclosed in the collodion membrane showed a section of cortical bone surrounded by serum and pus cells but no fibrous tissue. The margins of the bone were irregular and showed signs of absorption. The marrow was necrotic, and blood vessels, osteoblasts or osteoclasts were not present. The bone was apparently dead, although the lacunae still contained nuclei, probably because they had not had time to undergo degeneration.



Fig. 8 (dog 7).—Section of dorsal transplant enclosed in colloidal membrane. *A*, space formerly occupied by membrane; *B*, fibrous tissue outside membrane; *C*, osteoclasts; *D*, blood vessel containing red blood cells inside membrane; *E*, empty lacunae in cortical bone. Leitz, oculars, 2; objective, 2/3; bellows, 15 inches.

The transplant from the back that was not enclosed by a membrane was of similar appearance. In some places there was fibrous tissue along the margins of the bone, but neither osteoblasts nor osteoclasts were present. The bone showed marked erosion, and the marrow was necrotic. Although the lacunae contained nuclei, the segment appeared to be dead.

The unenclosed transplant in the abdomen showed only a rectangular strip of fibrous tissue.

The transplant from the abdomen enclosed in the collodion membrane was lost during the preparation of the microscopic sections.

COMMENT

In the experiments in which the transplants were enclosed in membrane, the presence of blood vessels inside the membrane was interpreted as an indication that the membrane had not remained intact. The onion membranes used in dogs 3 and 6 remained intact, and in neither of these cases were there any evidences of healing. Neither osteoblasts nor osteoclasts were present, and the bone itself was dead. The collodion membranes did not remain intact in any case, and there was a proliferation of fibrous tissue and blood vessels into the marrow cavity of the transplants in each case. In only one of this group, dog 5, was there any evidence of new bone formation. In only two cases, dogs 1 and 5, did the lacunae of the cortical bone appear to contain living cells, and these were the only specimens found to contain osteoblasts and show signs of osteoblastic activity.

Every specimen showed signs of absorption. In half the cases osteoclasts were present, and in these cases the process appeared to be one of typical rarefying osteitis. In the remaining cases and to some extent in the group previously mentioned, the process appeared to be one of simple absorption, halisteresis. Osteoclasts were not present in any cases in which the bone was enclosed in onion membrane. In only one case, dog 7, were osteoclasts present after the transplant had been killed by boiling, or after enclosure in a collodion membrane.

Microscopically, there was no apparent difference between the osteoclasts found along the edges of the bone and the foreign body giant cells which attacked the collodion membrane. The greatest amount of erosion was seen in the specimen from the back, which became infected and which at necropsy had been found in the middle of an abscess.

In dog 7, the boiled and unboiled transplants appeared exactly similar after having been enclosed in collodion membranes. Healing did not occur in either case, in spite of the fact that the membranes broke and fibrous tissue grew around the bones. This might indicate that death had occurred in the living transplant before the membrane weakened and permitted the penetration of fibrous tissue.

The marrow was usually replaced by fibrous or fatty tissue although occasionally, patches of lymphoid marrow persisted.

Most of the living transplants used as controls died without showing any evidence of bone regeneration. The muscles of the back were apparently the location most favorable for the life of the transplant and formation of new bone. New bone formation in the abdominal cavity took place in only one instance. The transplants to the knee joint all died. This is not surprising, since it had been noted clinically that death occurs in loose pieces of bone and cartilage in a joint such as sometimes follow intra-articular fractures. Allison, Fremont, Smith

and Dailey⁷ showed that joint fluid is similar to blood plasma, except that in joint fluid the amount of protein is slightly lower and the amount of chlorides greater. Experimental observations on the fate of bone and cartilage in joints do not agree. Strangeway⁸ expressed the belief that articular cartilage derives its nutriment from synovial fluid and that loose cartilagenous bodies not only survive in the joint cavities but may also increase in size. Haas² found new bone in transplants enclosed in perforated rubber tubing which had been inserted into the knee joint, but in every experiment the tube with its contents was adherent to the synovial membrane. Ito⁹ found some cartilage proliferation and slight formation of new bone. On the other hand, Fisher¹⁰ never found any sign of proliferation of the osteoblasts with the formation of new bone. It would seem that a bone segment in a joint cavity is not in a favorable location for viability and proliferation unless it becomes enclosed in fibrous tissue and circulation is established.

CONCLUSIONS

New bone formation in rib transplants occurs only in segments transplanted alive and only when the transplant itself becomes surrounded by well vascularized fibrous tissue. Death of the transplant invariably occurs when a membrane prevents the ingrowth of fibrous tissue and blood vessels, and is frequent under the most favorable conditions. In cases in which new bone formation occurs, the lacunae of the transplant, at least about the peripheral areas, contain darkly staining nuclei, and osteoblasts are present in fairly large numbers. Absorption of the bone begins immediately.

7. Allison, Fremont; Smith, and Dailey: *J. Bone & Joint Surg.* **8**:758, 1926.

8. Strangeway, S. P.: *Observation on the Nutrition of Articular Cartilage*, *Brit. M. J.* **1**:661 (May) 1920.

9. Ito, K. L.: *The Nutrition of Articular Cartilage and Its Method of Repair*, *Brit. J. Surg.* **12**:31 (July) 1924.

10. Fisher, A. G. T.: *Study of Loose Bodies Composed of Cartilage or of Cartilage and Bone with Special Reference to their Pathology and Etiology*, *Brit. J. Surg.* **8**:493, 1921.

SUBASTRAGALAR ARTHRODESIS *

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For many years arthrodesis, or surgical fixation of a joint, has been the method most commonly used to overcome deformity and to restore stability in a foot the function of which has been disturbed by paralysis, fracture or disease. In fact, this method is the only reliable means of securing and maintaining correction of a deformity. Arthrodesis necessitates the sacrifice of a joint, but such a loss is of little consequence as compared to the benefit derived from the stabilizing process. Motion that cannot be controlled is useless. There are several joints in the foot that may be destroyed without materially impairing the flexibility. The joints on which arthrodesis is most often performed are the ankle, the subastragalus and the midtarsal. This paper is concerned with fixation of the subastragalus joints.

The object of a subastragalus arthrodesis is to improve the function of an unstable foot, first, by stabilizing the joints below the astragalus, and second, by restoring the proper mechanics of the foot. Lateral deformity is controlled by fixation of the subastragalus joints. Balance is restored by displacing the foot backward, thus establishing a new weight-bearing line. The majority of methods of fixation in use today secure stabilization, but either they totally disregard the important principle of backward displacement of the foot, or they do not provide for sufficient displacement. This step is essential to the ultimate success of the operation.

The method devised by me allows displacement of the foot backward to any degree desired. At the same time, it ensures stabilization by producing ankylosis of the calcaneo-astragalus joint and the midtarsal joints. The technic is simple and affords a good surgical exposure. Deformity may be corrected at the time that the arthrodesis is being done. Talipes varus or talipes valgus may be overcome by planning the angle at which the section of bone is removed from the lower part of the body of the astragalus. Cavus, which often cannot be corrected in the presence of paralysis of the gastrocnemius muscle, may be overcome when stabilization is done.

INDICATIONS FOR OPERATION

Subastragalus arthrodesis is used when the balance and stability of the foot have been disturbed by paralysis, joint fracture or joint disease. It is the custom of some surgeons to correct congenital clubfoot by this

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* From the MacAusland Orthopedic Clinics.

procedure, but its applicability in such cases is questionable. Gill,¹ who writes on the use of this operation in congenital cases, says that he uses manipulation and casts when possible but that when the feet are too old and rigid to be thus relieved, subastragalar arthrodesis is used. Furthermore, in congenital cases a perfect functioning foot may be obtained by the use of other reliable methods.

A fixation operation may be used in deformities and disabilities resulting from infantile paralysis, in which stability still remains at the ankle joint, but in which there is insufficient muscle control because of hypermobility in the midtarsal and calcaneo-astragalar joints. The operation is applicable in paralytic talipes valgus, varus, calcaneus, cavus and in some cases of flail-foot. In talipes equinus, a subastragalar arthrodesis may be used in conjunction with the construction of a bone block to limit plantar flexion.

In talipes valgus or varus, correction of the lateral deformity may be secured at the time of arthrodesis by directing the slant of the saw to allow the removal of a larger section of bone from the outer or inner side of the astragalus. If there is a slight element of equinus associated with the valgus or varus, it is indirectly controlled by overcoming the lateral deformity. In valgus deformity associated with calcaneus, stability and function are materially increased by transplanting the peroneal tendons into the achilles tendon in conjunction with the subastragalar arthrodesis.

In talipes calcaneus, the value of a subastragalar arthrodesis lies in transferring the body weight forward on the foot. When my technic is used, it is possible to displace the foot backward to any degree, thereby changing the weight-bearing surface through the tibia and fibula from directly over a perpendicular *os calcis* forward to about the mid-tarsal region. Cavus, which is present in most cases of talipes calcaneus, can be corrected by the removal of a tarsal wedge. This step also helps in restoring the *os calcis* to a normal position. When the peronei and *tibialis posticus* are active, they should be transplanted into the *os calcis*. In this position, the muscles will increase the function of the foot and aid plantar flexion.

Paralytic cavus, which is always corrected with difficulty by the customary methods and which frequently cannot be overcome, may be corrected at the time of a subastragalar arthrodesis by removing a wedge from the plantar section with its apex toward the plantar surface (cases 6, 7 and 8).

A person with a flail-foot is most disturbed by the dropping of the forefoot, which forces him to lift his foot high to avoid tripping. A

1. Gill, A. B.: Fusion Operation on Foot, *J. A. M. A.* 89:1829 (Nov. 26) 1927.

subastragalar arthrodesis, by tending to equalize the weight of the anterior and posterior parts of the foot, prevents this dropping of the foot. At the same time any tendency to lateral deformity is overcome. The results of subastragalar arthrodesis in cases of flail-foot are particularly gratifying if any power remains in the anterior group of muscles.

In cases of flail-foot, in which there is a great amount of laxity in the tibio-astragalar joint, subastragalar arthrodesis is not advisable. In such cases, astragalectomy is to be preferred. The resulting shortening in an astragalectomy, if properly done, does not amount to more than one-half inch and can be easily compensated. In a paralytic subject, shortening of from one-fourth to one-half inch is of little importance, provided stability is established.

Subastragalar arthrodesis occasionally is advisable in a case of spastic paralysis, but the procedure should be used only after careful



Fig. 1.—Fracture dislocation with traumatic bony changes in adjacent parts; subastragalar arthrodesis was advised.

consideration. One always hesitates to perform arthrodesis in the presence of neuromuscular lesions of the spastic variety. The operation will not affect the spastic condition, which is of central nervous origin. If the foot has been pulled into valgus position originally, the pull undoubtedly will continue after operation. If the pull into deformity is constant, relaxation in the capsular ligaments of the ankle joint is liable to take place, with a subsequent recurrence of deformity.

In fractures of the astragalus, scaphoid and os calcis, in which the joint line between these bones has been destroyed, or in which the joints are unduly strained as the result of faulty mechanics following fracture, subastragalar arthrodesis is the rational method of relief. These fractures may cause great disability because they are painful and limit motion. Not infrequently they are accompanied by dislocation.

Figure 1 shows a fracture dislocation with traumatic bony changes in the adjacent parts, for which a subastragalar arthrodesis was advised.

In marked flatfoot with paralysis of all the supinator muscles, a subastragalar arthrodesis may be used to restore the muscle balance. Mayer² supplements this operation by a transplantation of the peroneus longus into the tibial insertion for flatfoot. The valgus deformity is corrected at the same time by tilting the wedge that is removed.

In Chopart's amputation, subastragalar arthrodesis may be used to prevent the achilles tendon from pulling the os calcis way back.

In tuberculous cases, in which the disease is located in the subastragalar joints alone, a subastragalar arthrodesis may be indicated. Fixation can control the tuberculous process provided it is isolated. The difficulty is that usually more than one bone is involved. In tuberculous cases of the foot in which the condition has healed with fibrous ankylosis of the joints, subastragalar arthrodesis may be used to secure bony ankylosis. Firm fixation of the joints relieves pain and stabilizes the foot.

Age.—It is generally agreed that arthrodesis should not be performed before the child reaches maturity, usually at about the age of 16 years. At this age, the bones are sufficiently ossified to assure the formation of a true bony ankylosis.

The prevailing opinion that arthrodesis is inadvisable before the age of 16 years undoubtedly is due to the fact that many failures have resulted from attempts to perform arthrodesis in younger children. It is probable, however, that true bony ankylosis was not obtained because the operative technic did not allow sufficient exposure and did not provide for the removal of enough cartilage. When my method is used, these difficulties are not encountered, for it assures bony union by bringing the freshened bone surfaces into perfect apposition and contact. It also eliminates any danger of the parts slipping while a plaster cast is being applied. If this technic is used, arthrodesis may be done before the patient has reached the age of 16 years, but it cannot be carried out with assurance of success in patients below 12 years of age.

TECHNIC OF OPERATION

So far as possible, deformity should be corrected before operation. Careful preparation is made and a tourniquet applied. A semicircular incision is made, beginning on the dorsum of the foot in the region of the astragaloscaphoid joint, curving under the external malleolus and terminating over the achilles tendon. To avoid cutting the ligaments between the astragalus and the fibula, it is well to make the incision low enough to pass over the joint between the astragalus and the os calcis (fig. 2). The skin and fascia on each side are dissected back. If the dorsal extensor muscles are functioning, their tendons are retracted to the dorsum of the foot; if these muscles are totally paralyzed, the tendons may be severed with

2. Mayer: Am. J. Surg. 38:289, 1924.

impunity. The capsule over the astragaloscapoid joint is opened to allow displacement of the head of the astragalus. The ligaments between the astragalus and the os calcis are then severed, and the capsule over the calcaneostragalar joint is incised. The sole of the foot is strongly inverted. The ligaments on the inner side of the astragalus are dissected upward to allow the entire body of the astragalus to appear in the wound. Care should be taken not to disturb the ligamentous attachments of the tibia, fibula and astragalus.

If cavus is present, the next step is to remove a V-shaped wedge from the lower tarsus, with its apex toward the plantar surface and its base toward the astragalus.

Then, with a saw held parallel to the body of the astragalus, from three-eighths to one-half inch of the lower part of the body of the astragalus is removed (fig. 3). A corresponding section of bone is removed from the scaphoid and midtarsal region, running back to the tip of the os calcis, from which the

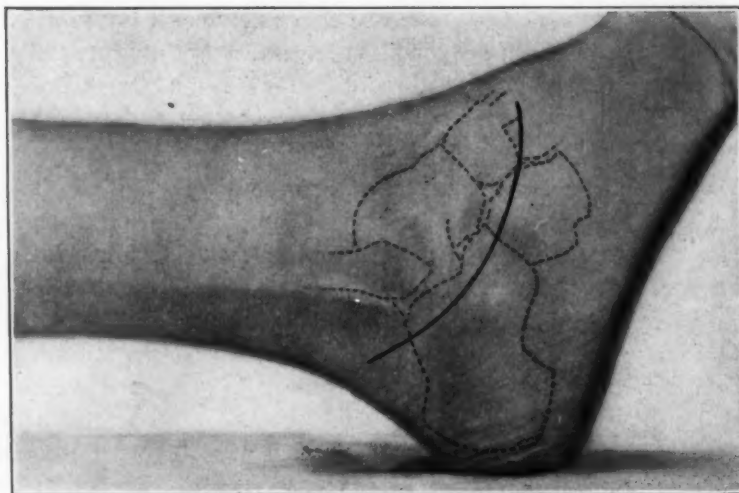


Fig. 2.—Subastragalar arthrodesis with incision around the external malleolus.

cartilage is excised (fig. 4). The opposing surfaces are now approximated carefully, and the desired degree of varus, valgus and posterior displacement determined (fig. 5). When the foot has been displaced posteriorly, it will be noted that the anterior superior part of the head of the astragalus bulges. A small wedge of bone may be removed to do away with this prominence. The wound is closed in the usual manner.

A plaster bandage is applied, extending from the toes to above the knee, with the foot held as near a right angle as is practicable, and in good posterior displacement. At the end of three weeks, the section covering the knee is removed, and weight-bearing is allowed. The plaster bandage may be changed as necessary, but a cast should be worn for ten or twelve weeks. When the cast is removed, a flannel bandage and an ordinary boot are all the support necessary.

In calcaneus and equinus deformities, this technic may be supplemented by the construction of a bony process to limit dorsal or plantar

flexion. Campbell³ has devised a method for the correction of drop-foot, whereby a bone block is created on the superior surface of the os calcis. This process limits plantar flexion by impingement on the posterior surface of the tibia. In cases of talipes calcaneus, Gill² recommends the construction of a bone block on the anterior aspect of the superior articular surface of the astragalus.

I have not had any experience with the use of bone blocks. If the loss of muscle control is sufficient to warrant a measure of this nature, astragalectomy is perhaps to be preferred to a subastragalar

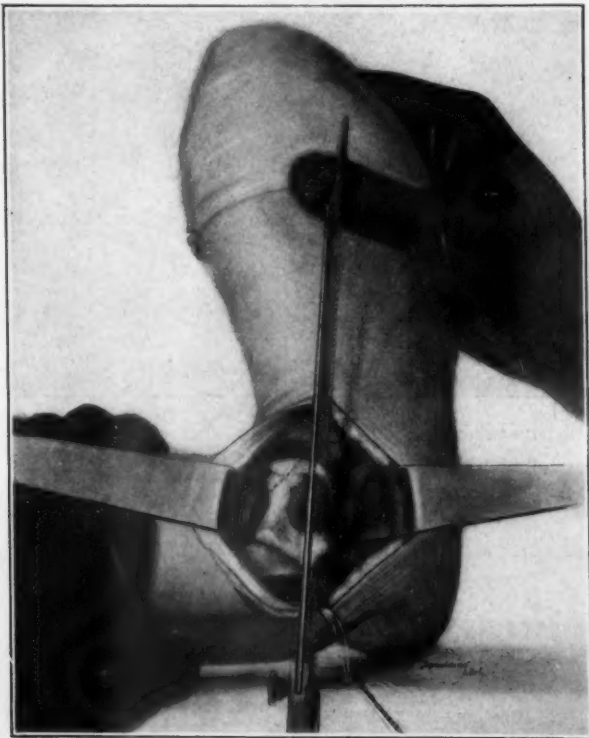


Fig. 3.—Subastragalar arthrodesis with removal of a transverse section from the lower third of the astragalus.

arthrodesis. The results obtained in the use of bone block by other operators, however, have been promising, and indications are that the constructed processes will act as permanent means of preventing deformity.

A comparison of the technic already outlined with other procedures in use, of which the most well known is the Hoke⁴ operation, will show

3. Campbell, W. C.: End-Results of Operation for Correction of Drop-Foot, *J. A. M. A.* **85**:1927 (Dec. 19) 1925.

4. Hoke: *J. Orthop. Surg.* **3**:494, 1921.



Fig. 4.—Subastragalar arthrodesis with the removal of a transverse section from the tip of the os calcis through the top of the tarsal region.

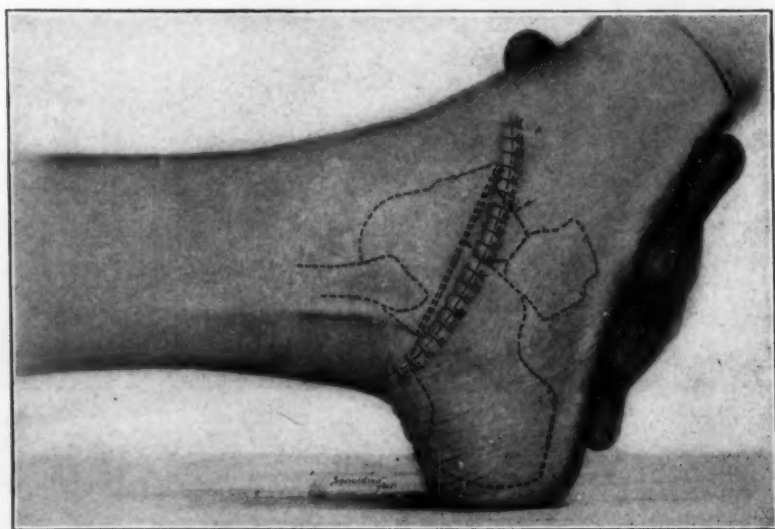


Fig. 5.—Subastragalar arthrodesis with posterior displacement of the tarsus on the astragalus.

that my method has certain advantages over other measures. The technic is simple, affords good exposure and assures a firm ankylosis. The important step of the operation—the backward displacement of the foot—can be carried out to any degree desired.

The technic devised by Davis⁵ is no longer in use, but his principles form the basis of the procedures employed today. Several modifications of the Davis method have been worked out. In general, their technic is complicated and requires a great deal of accuracy. It is difficult to secure backward displacement of the foot.

Hoke's procedure is essentially the same in principle as the Davis method. The skin incision extends from over the external portion of the head of the astragalus downward and backward to the peroneal tendons below the end of the fibula. The adipose tissue of the "sub-astragaloid fossa," that is, the space bounded above by the neck of the astragalus, below by the superior surface of the os calcis and behind by the body of the astragalus, is split. Its upper and lower portions are dissected out, leaving the under surface of the neck and the adjacent portion of the body of the astragalus and the superior surface of the os calcis bare. With a knife, the superior surface of the neck of the astragalus is denuded of tissue. The head of the astragalus is freed from the scaphoid, by cutting the astragaloscaphoid ligament, beginning low and externally and sweeping around the head, and ending internally. A portion of the inferior surface of the body of the astragalus and a portion of the adjacent surface of the os calcis are removed. The neck of the astragalus is cut through where it joins the body. The head of the astragalus is levered partly out, and the remaining attachments are cut with scissors. The neck and the head of the astragalus are placed in a towel. The scaphoid and the facet on the superior surface of the os calcis are denuded of cartilage. The deformity of the posterior part of the foot may now be corrected as required; the posterior end of the os calcis may be set in line with the center of the leg, the os calcis may be shifted laterally in line with the central axis of the leg, lateral rotation of the os calcis may be corrected and the foot may be shifted backward.

The head of the astragalus is denuded of cartilage. The position in which the astragalus is replaced depends on the type of paralytic foot; it is put back in a different position for drop-foot, clubfoot, and flatfoot. In simple drop-foot, for instance, the astragalus is too long to go back in its place when the anterior foot is cocked up. The astragalus is held on a wooden block, and with a hammer and osteotome, just enough of the posterior end is removed so that the piece of bone sinks in neatly between the scaphoid and the body of the astragalus without hindering the cocking up of the anterior foot.

5. Davis: *Internat. Clin.* 4:20, 1917.

After the astragalus has been replaced, the foot is brought into slight dorsiflexion. The assistant sews the subcutaneous tissues with interrupted No. 1 catgut sutures, and the skin with interrupted silk sutures. A plaster bandage is applied from the toes to the knee.

If it is not possible to correct the downward pitching of the shafts of the metatarsals to the degree desired, a manipulation may be done, the foot being forced downward and the anterior ends of the metatarsals upward.

The complexity of this procedure is readily seen. The removal of part of the neck of the astragalus and its return to a correct position is a step that requires a great deal of accuracy, and one that is attended with risk. While the procedure assures stabilization of the subastragalar joints, it does not provide for easy backward displacement of the foot.

I have used my technic in eight cases with satisfactory results. In five cases, a subastragalar arthrodesis alone was performed. In the other three cases, a V-shaped wedge was removed from the mid-tarsal joint in conjunction with the subastragalar arthrodesis.

REPORT OF CASES

CASE 1.—History.—M. K., aged 4 years, complained of paralysis of both feet with deformity of two years' duration. The condition was the result of infantile paralysis.

Examination.—The results of general examination were negative. Of the muscle groups, the iliopsoas and quadriceps in the right leg had good power; the anterior and posterior tibial muscles were without power. The patient stood with the foot in marked valgus position and pronation. The posterior tibial muscle in the left leg was present, but weak. The anterior tibial muscle did not have any power. The foot was in moderate pronation. Both feet showed some toe-drop.

Treatment.—The previous treatment had consisted of massage and muscle training. The patient had also worn Thomas heels. On March 14, 1919, a double astragaloscaphoid arthrodesis was performed, and splendid overcorrection was obtained. One year after operation, the patient walked with the ankles in good position. At this time, Whitman braces and a Thomas heel and sole were being worn on the right foot. During the next year, the achilles tendons of both feet showed a tendency to contract.

On July 27, 1920, both tendons were taut, allowing motion to only a right angle. The right foot was in slight valgus position. Except for the contraction of the achilles tendon, the left foot was in good position.

Tenotomies of both achilles tendons were performed on September 29. Two months later, both feet were straight, although the right foot still showed a tendency toward valgus position.

One year later, Sept. 30, 1921, there was a relapse of the condition of the right foot, and a second astragaloscaphoid arthrodesis with a Gallie fixation of the anterior tibial muscle into the tibia was performed. From this time on, the patient held her feet in good position and walked better.

On June 20, 1923, both arches were perfectly formed. The left foot was in excellent position. The right foot was straight, but there was a slight tendency to

pronation. The peronei and outer dorsal flexors in this foot were unusually strong. Although it was thought that the patient could voluntarily overcome the pronation, this was found to be impossible.

On March 1, 1924, she was walking with both feet pronated, especially the left. There was considerable eversion of both legs. The patient was knock-kneed about 10 to 15 degrees, and in walking, the knees interfered—a factor that contributed to the outward rotation.

The condition grew worse. By April 30, the patient walked with considerable valgus. The midtarsal joints, however, were holding firmly. In both feet, all muscles with the exception of the anterior tibials had power.

A double subastragalar arthrodesis was performed on June 18.



Fig. 6 (case 1).—Valgus deformity of both feet. Anteroposterior view eight months after subastragalar arthrodesis of both feet.

On October 10, the feet were in excellent position, and the patient walked well. The condition continued to improve. Figure 6 shows the result eight months after operation.

CASE 2.—History.—M. H., aged 3 years, complained of lameness of the left foot of one year's duration, which was caused by an attack of infantile paralysis.

Examination.—All muscles of the left foot with the exception of the gastrocnemius had some power (fig. 7).

Treatment.—For about eight weeks, the child had worn a shoe with an upright and reverse stop-joint, but power had not returned in the gastrocnemius muscle. On Sept. 30, 1924, a subastragalar arthrodesis and a tenotomy of the plantar fascia were performed.

On December 23, a good displacement had been obtained. The shortening was compensated by a raise on the heel and sole. Figure 8 shows the position of the foot, one year and seven months after operation.

Two years later, December, 1926, the foot had a tendency to go into slight calcaneus position. There was plantar flexion to only a right angle. The riding of the first metatarsal prevented the joint from reaching the floor.

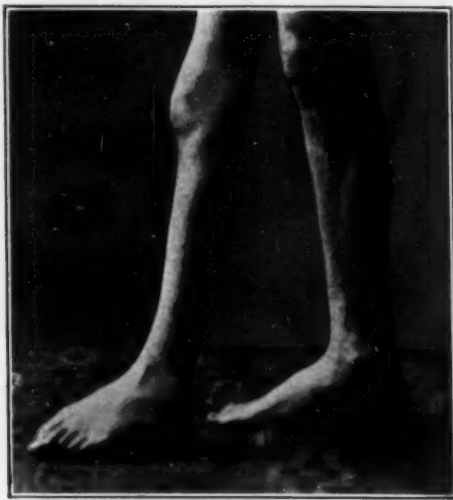


Fig. 7 (case 2).—Lateral view of calcaneocavus deformity of the left foot before operation.



Fig. 8 (case 2).—Correction of calcaneocavus deformity of the left foot one year and seven months following subastragalar arthrodesis.

An osteotomy was done on March 15, 1927, to swing the metatarsal down. The result was excellent, and the patient stood with the foot in splendid position.

On November 22, the foot showed slight varus. Manipulation was done for correction with the patient under ether.

On Feb. 21, 1928, a brace held the foot in correct position.

CASE 3.—History.—T. L., aged 9 years, complained of paralysis of the right foot of seven years' duration. At the age of 2 years, the patient had an attack of infantile paralysis which affected practically the entire right side. The greatest residual weakness was located in the right leg and foot, and the patient limped when he walked.

Examination.—The muscle groups of the right thigh were present, but weak. The muscles of the leg, with the exception of the gastrocnemius and the posterior tibial, had some power. There was some cavus deformity (fig. 9).

Treatment.—July 27, 1922: The achilles tendon was shortened by open operation, and a plaster bandage was applied with the foot in plantar flexion. The plaster was worn for twelve weeks; then an inner upright with a reversed stop-joint permitting plantar flexion to 7 degrees was applied to the shoe. Massage was given for three weeks after the removal of the plaster.



Fig. 9 (case 3).—Lateral view of calcaneocavus deformity before operation.

On March 24, 1923, there was some power in the gastrocnemius, and the contour of the foot was better. The brace was discarded, and the foot was strapped in slight plantar flexion.

During the next few weeks a definite spastic condition developed. The child walked with the right foot in valgus deformity. The gait was shuffling, probably owing to the mild meningeal infection.

One year later, March 14, 1924, the patient still walked with the foot in valgus position, and the os calcis was tilted posteriorly. The achilles tendon was not so lax as formerly. The peronei were definitely spastic. Spiral strapping was applied to hold the foot in varus. The foot was restrapped several times at intervals of two weeks, but without relief.

On July 9, a subastragalar arthrodesis was performed according to my technic.

The plaster bandage was removed on October 4. The foot was in excellent position. The patient was advised to wear a shoe to which an outer upright with a right-angle stop-joint was attached.

Nearly one year after operation, Aug. 1, 1925, the patient was walking well without a brace. The foot was in excellent position (fig. 10).

CASE 4.—History.—J. M., aged 14 years, complained of lameness of the left foot, following an attack of infantile paralysis.

Examination.—The child stood and walked with the left foot in varus position. The left leg was one-half inch shorter than the right and was cold. The plantar fascia was taut. Neither peronei nor outer dorsal flexors remained.

Treatment.—April 23, 1928: The foot was manipulated into valgus position, and the achilles tendon was stretched. A cast was applied from the toes to above the knee. The section covering the knee was removed in a month, and the child was allowed to walk. Later, when the rest of the cast had been removed, a lift was worn on the outer side of the heel and sole. The plantar fascia was still taut, but further operative treatment was deferred because of a septic condition. Mean-



Fig. 10 (case 3).—Correction of calcaneocavus deformity one year after subastragalar arthrodesis.

time, the patient wore a shoe equipped with an inner upright, outer T-strap and stop-joint at a right angle.

Manipulation under ether, fasciotomy, and tenotomy of the achilles tendon were done on Jan. 20, 1920.

On February 24, another tenotomy of the achilles tendon was performed, and a plaster bandage was applied. The patient walked on the plaster during the next two months.

On May 18, a new cast was applied, and remained on for two months. The cast was removed August 10. A good correction had been obtained.

During the next five years, the foot continued to hold in fairly good position, but a tendency to cavus developed. A subastragalar arthrodesis was advised.

Operation was performed on Sept. 27, 1925. A cast was applied and worn for ten weeks. On Nov. 24, 1925, good displacement had been obtained.

On December 22, the boy stood with the foot in excellent position. The left shoe was raised three fourths of an inch on the heel and one-half inch on the sole with a bevel of two eighths of an inch at the toe (fig. 11).

The following February, a pressure ulcer developed under the fifth metatarsal head.



Fig. 11 (case 4).—Correction of varus deformity of the left foot three months following subastragalar arthrodesis.

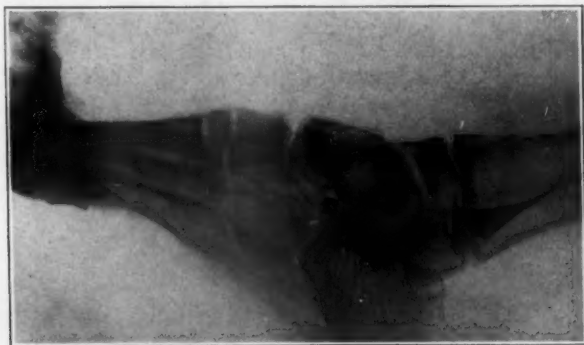


Fig. 12 (case 4).—Lateral view showing correction of varus deformity of the left foot two years after subastragalar arthrodesis.

In December, 1926, it was noted that an equinovarus was developing. Manipulations were advised.

On March 15, 1927, an anterior wedge osteotomy was performed to correct plantar flexion of the forefoot and to relieve weight-bearing on the metatarsal heads. Treatment of the callus was continued.

On August 30, an inner upright with outer T-strap was being worn on the shoe. The patient was advised to have sun treatments and manipulation. The foot was in excellent position (fig. 12).

CASE 5.—*History.*—J. B., aged 12 years, complained of pain in the legs of seven years' duration. The patient fell when 5 years of age, and the legs had pained since that time. There was no history of any illness.



Fig. 13 (case 5).—Lateral views four and one-half years after subastragalar arthrodesis.



Fig. 14 (case 5).—Anteroposterior view four and one-half years after subastragalar arthrodesis.

Examination.—The child stood with both feet flat and abducted. The general condition was normal.

Treatment.—Conservative methods were used at first. Whitman braces, shoes with Thomas heels and foot exercises were prescribed.

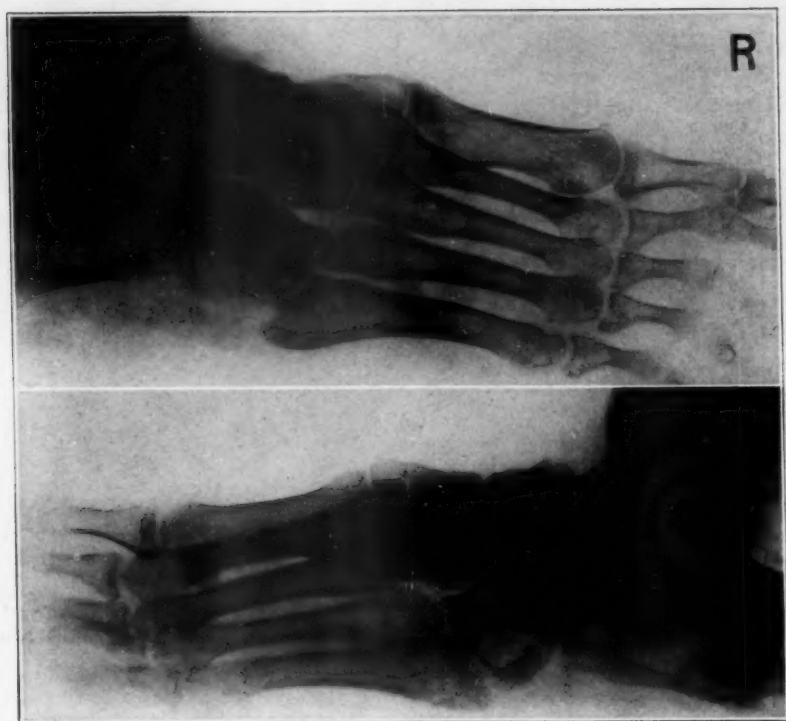


Fig. 15 (case 5).—Results of double subastragalar arthrodesis.



Fig. 16 (case 6).—Lateral view showing calcaneocavus deformity before subastragalar arthrodesis.



Fig. 17 (case 6).—Roentgenogram showing lateral view seven months after subastragalar arthrodesis for calcaneocavus deformity.

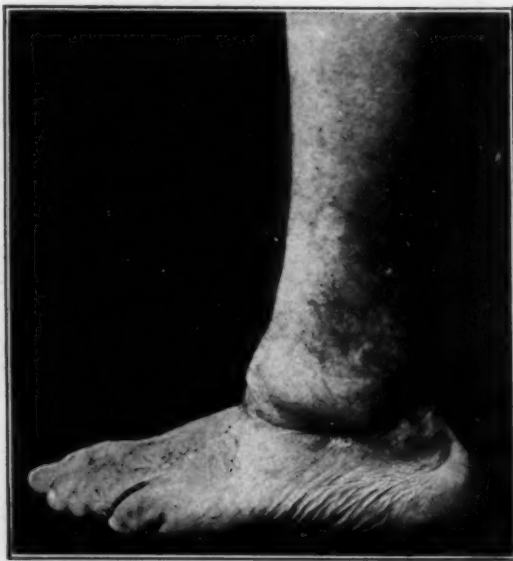


Fig. 18 (case 6).—Lateral view seven months after subastragalar arthrodesis for calcaneocavus deformity.

A subastragalar arthrodesis was performed on June 19, 1923. On August 14, the plaster cast was removed. A good overcorrection had been obtained. The feet were strapped in valgus position. Restrapping was done once a week during the next month.

On October 9, the patient stood with the feet in excellent overcorrection. A slight tendency toward varus deformity was decreasing. The child did not have any pain.

In January, 1928, four and a half years after operation, both feet were stable. The patient could rise up on the toes and dance. There was some flattening of the feet. The result was excellent (figs. 13, 14 and 15).



Fig. 19 (case 7).—Roentgenogram showing foot in plaster bandage three weeks after subastragalar arthrodesis for cavus deformity.

CASE 6.—History.—H. R., aged 23 years, complained of lameness which had been present for a period of twenty-one and a half years. The condition was caused by infantile paralysis.

Examination.—The left foot showed a calcaneocavus deformity (fig. 16).

Treatment.—On Jan. 14, 1925, subastragalar arthrodesis was performed according to my technic, and a V-shaped wedge was taken out of the midtarsal region.

On February 9, the foot was in excellent displacement. There were signs of union in the subastragalar joints.

The plaster bandage was removed March 9, and an outer upright with an inner T-strap was applied to the shoe.



Fig. 20 (case 7).—Photographs taken three months after subastragalar arthrodesis for cavus deformity.



Fig. 21 (case 7).—Roentgenogram showing lateral view eight months after subastragalar arthrodesis for cavus deformity.



Fig. 22 (case 8).—Lateral view showing calcaneocavus deformity before operation.

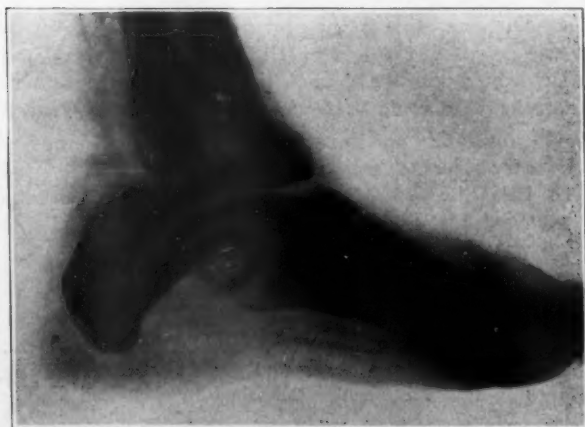


Fig. 23 (case 8).—Lateral view ten months after subastragalar arthrodesis for calcaneocavus deformity.

The roentgenogram and photograph taken August 24 (figs 17 and 18), seven months after operation, show an excellent result.

CASE 7.—History.—D. B., aged 10 years, walked with a limp in the right leg. The condition, which was of long standing, followed an attack of infantile paralysis.

Examination.—On Oct. 16, 1923, the patient stood with a total left scoliosis. The left leg was about one-fourth inch shorter than the right and was blue and mottled in its lower half. All the muscles of the leg with the exception of the gastrocnemius had slight power. The forefoot was broad, and the plantar fascia was tense and hard. The foot showed cavus deformity.

Treatment.—A tenotomy of the plantar fascia was done in October, 1923. For more than two years, the patient wore a boot with a built-up heel and sole, which was adjusted when required.

Physical examination on April 28, 1925, did not show evidence of return of power in the gastrocnemius muscle. The foot was painful, and the cavus deformity seemed to be increasing. The deformity in the forefoot was of about 80 degrees. A tenotomy of the plantar fascia and stretching were done. A plaster bandage, reinforced on the sole, was applied as far up as the knee. Weight-bearing was begun in three days.

On June 23, a subastragalar arthrodesis with removal of a plantar V-shaped wedge was performed. A plaster bandage was applied, the lower part of which was to be worn for ten weeks; the upper part was removed at the end of ten days. Walking was allowed in four weeks (fig. 19).

On August 18, the foot was in excellent position. There was good motion in the ankle joint. Photographs (fig. 20) taken September 29, and a roentgenogram (fig. 21) taken eight months after operation, show the excellent position of the foot.

CASE 8.—History.—E. K., aged 35 years, complained of pain in the ankle. The condition was of long standing and was gradually becoming worse. When 17 months of age, the patient had suffered from an attack of infantile paralysis, which involved both lower limbs. The residual paralysis was localized in the left foot. When he was 18 years of age, an arthrodesis had been performed in a New York hospital.

Examination.—On Aug. 4, 1925, the foot was in the position of calcaneocavus, and the patient suffered from the deformity (fig. 22). A subastragalar arthrodesis was advised, which would push the os calcis backward and make it more horizontal. At the same time, the cavus could be corrected by removing a subtarsal wedge.

Treatment.—The operation was performed on Nov. 12, 1925, and a bony wedge was removed from the subtarsal region.

On Sept. 26, 1926, the arthrodesis was perfect. There was no deformity. Function had improved, and the patient walked well. Figure 23 shows the good displacement that was obtained.

All the illustrations used in this article, except figures 1, 11, 12, 13, 14, 15, 22 and 23, have been taken from MacAusland's book, entitled, "Poliomyelitis, with Especial Reference to the Treatment," published by Lea and Febiger.

ALLERGY AS A FACTOR IN THE PRODUCTION OF PROLIFERATIVE ARTHRITIS *

JOSEPH A. FREIBERG, M.D.

CINCINNATI

In spite of the abundant literature on chronic nontuberculous arthritis, its etiology has remained obscure. The numerous authors who have classified this disease agree that it may be subdivided into two main types differentiated in the clinical and pathologic picture. One type is characterized by marked deformity and severe crippling and occurs usually within the first three decades of life. The other type has a far more insidious onset, rarely resulting in crippling, and usually occurs during the latter part of the fourth decade, or later. This paper deals with an experimental study of the first type, known as the proliferative type of Nichols and Richardson,¹ the atrophic type of Goldthwait,² the rheumatoid type of our British confreres, type I of Ely's classification,³ and as infectious or toxic arthritis by others.

In the orthopaedic department of the Children's Hospital of Boston, during a period of several years, a number of cases of nontuberculous, monarticular arthritis have been seen. The histories of these cases are surprisingly similar. Ten cases, seen during 1925 and the earlier months of 1926, have been chosen for careful consideration. In this series, an infection of the upper respiratory tract or, more frequently, a gastro-intestinal disturbance had existed several weeks prior to the onset of the joint symptoms. In seven cases the lesion was of the hip joint, and in three, of the knee joint. In each case the onset of the illness was characterized by a slight elevation of temperature, muscle spasm, varying degree of periarticular swelling of the soft tissues, pain in the affected joint, and in several instances, a palpable joint effusion. The intradermal tuberculin reaction was negative in dilutions of from 1:1,000 to 1:10,000, in six cases, and was not recorded in the remainder. X-ray films of the affected joint were

* Submitted for publication, Aug. 23, 1928.

* From the Orthopaedic Department of the Children's Hospital, Boston.

* Preliminary report read before the New England Pediatric Society, November, 1926, Boston.

1. Nichols, E. H., and Richardson, F. L.: *Arthritis Deformans*, J. M. Research **16**:149, 1909.

2. Goldthwait, J. E.; Painter, and Osgood, R. B.: *Diseases of the Bones and Joints*, Philadelphia, Lea & Febiger, 1909.

3. Ely, L. W.: *Inflammation in Bones and Joints*, Philadelphia, J. B. Lippincott Company, 1923.

negative, excepting for soft tissue swelling, in every instance. The total duration of signs and symptoms, in this series, varied from thirteen days to eight months. In the two patients in whom symptoms were of months' duration, the lesions had existed for fifty-four and sixty-three days prior to their first visit to the hospital. The therapy instituted was the same in principle in all cases, varying only with the special indications and depending on the age of the child. Two principles of therapy were utilized; regulation of feeding, and regulation of defecation by catharsis and abdominal massage. Of the ten cases, the maximum duration of signs and symptoms following admission was sixty-seven days in one case, while the average duration for the series was only twenty-six days. No recurrence of symptoms had appeared during the ensuing six months or longer, and clinically the affected joint could not be distinguished from the corresponding unaffected joint.

While several of the patients of the foregoing series were under observation, it was apparent that they formed a group of cases in an extremely early phase of the disease, and, therefore, were especially favorable cases for analysis. That the therapy was responsible for the rapid disappearance of symptoms seems probable, since, though some of these cases were of long standing, they were symptomless after a period of three or four days. This strengthens the hypothesis that some substance is either formed in the intestinal tract, or at least, absorbed from the intestinal tract in a certain type of case, and is a causative element in the production of joint symptoms. Many cases of chronic, proliferative arthritis show marked amelioration of symptoms following dietary regulation and improved intestinal elimination. In the majority of cases of chronic, nontuberculous arthritides, foci of infection exist elsewhere in the body, as Pemberton and Pierce⁴ have shown.

The purpose of the experimental procedures subsequently described was to determine if a bacterial extract made from bacteria generally supposed to be associated with certain cases of arthritis could produce lesions in animals similar to the so-called proliferative arthritis in man. Having obtained such an arthritis, an attempt was made to ascertain the nature of the reaction which occurred. In seeking an experimental approach to this problem, it seemed advisable to produce an arthritis by direct injection into a joint, thereby eliminating, as far as possible, unknown factors. The knee joint of the rabbit was chosen for this purpose. Medical literature contains numerous reports of arthritis

4. Pemberton, R., and Pierce, E. G.: A Clinical and Statistical Study of Chronic Arthritis, *A. J. M. Sc.* **173**:31, 1927.

associated with bacillary dysentery.⁵ In this hospital, Clifford⁶ found that of seven cases of polyarthritis in children, examined by culture and agglutination reactions, four showed the presence of either an existing infection with *B. dysenteriae*, or evidence of a recent infection. Because of the arthritis accompanying bacillary dysentery epidemics and the observations of Clifford, *B. dysenteriae* was chosen for the present study as an organism having the requisite arthrotropic qualities.

Six experiments were carried out on six separate series of rabbits, and subsequently these animals were used for variations of the original procedures. Twelve of the thirty-six rabbits used received intra-articular injections of a bacterial extract of *B. dysenteriae*, and the remainder received either intra-articular, subcutaneous or intravenous injections of the bacterial extract, lactic acid, horse serum or suspensions of living dysentery bacilli. An attempt was made to differentiate between the various factors associated with the introduction of a bacterial extract, such as the acidity or alkalinity of the solution, the presence of foreign protein, and sensitization of the animals to a specific bacterial substance. Because of the diversity of injection substances used, in each experiment, one or the other of the original series was utilized as a control. This was of greatest importance in interpreting the results of blood serum agglutination reactions and intradermal reactions.

PROTOCOLS

It is generally agreed that *B. dysenteriae* Flexner does not produce exotoxin, and for this reason *B. dysenteriae* Flexner Y Oxford standard culture strain was used. The twenty-four hour growth of this organism from forty-eight Blake bottle agar slants was suspended in 720 cc. of physiologic sodium chloride solution, placed in the incubator at 37 C. to allow autolysis, and twelve days later was filtered through a Berkefeld filter. Prior to filtration a slight but definite decrease in the opacity of the bacterial suspension was noted, and direct smears of this suspension showed a considerable amount of debris and poorly staining bacteria. The filtrate was then diluted with more saline solution until the total volume was 1 liter. This filtrate, after being tested and found to be sterile, was used as the bacterial extract already mentioned. At the beginning of the experiments the hydrogen ion concentration of this extract was 7.55, as determined by a potentiometer, and at the termination of these experiments, five months

5. Conner, R. D., and Bates, L. B.: *Internat. Clin.* **4**:36, 1924. Manson-Bahr, P.: *Brit. M. J.* **1**:791, 1920. Waller, W. E.: *Lancet* **2**:778, 1919. Klein, B. G.: *Lancet* **2**:775, 1919. Graham, G.: *Proc. Roy. Soc. Med. (med. sec.)* **13**:23, 1919. Cowan, J. M., and Miller, H. Roy: *Arm. Med. Corps.* **31**:216 and 277, 1918.

6. Clifford, S. H.: *Rôle of Dysentery Bacillus in Arthritis Deformans*, *Am. J. Dis. Child.* **32**:72 (July) 1926.

having elapsed, the hydrogen ion concentration was 7.8. A second batch of bacterial extract with a p_H of 4.58 was made and used on one rabbit. I mention this fact because the two extracts differing widely in hydrogen ion concentration gave identical results in rabbits.

For intra-articular injections, a routine procedure was used. The rabbits were placed on their backs and held by metal clamps attached to their elbow and ankle joints, in such a manner that the hind legs were fully extended. In this position the patella lay in the intercondylar fossa of the femur. By carefully introducing a small caliber hypodermic needle directly through the patellar tendon in the anteroposterior plane, without trauma to the articular surfaces, and with satisfactory fixation of the needle by the tendon, fluid was inserted beneath the patella and within the joint space. By preliminary experiments on dead rabbits weighing from 1,500 to 2,000 Gm., I had found that from 1 to 1.5 cc. of fluid could be introduced with ease, and without undue distention of the capsule. Successful intra-articular injections into the knee joint were indicated by an absence of resistance to the injected fluid until the joint capsule was palpable as a distended, fluctuant mass. Injections into the elbow were made in a similar manner, excepting that the needle was introduced between the internal humeral condyle and the olecranon, with the fore leg externally rotated.

SERIES I.—Series I consisted of nine rabbits, eight of which were run simultaneously using the same bacterial extract, while the ninth received a more concentrated bacterial extract at slightly more frequent intervals. The right knee joint was used for the injections of bacterial extract and the left for control injections of saline. Three of the nine rabbits showed a minimal reaction following the second injection, and one, in which the more concentrated bacterial extract was used, showed a slight reaction after the first injection, but of a markedly less degree than that shown on subsequent injections. In no rabbit was there a reaction in the left knee following the introduction of sterile, physiologic sodium chloride solution. Table 1 shows the degree of the articular reactions, the number of injections, and the interval of time between injections for this series. Following the initial reactions in the joints, subsequent injections of the extract invariably caused a marked peri-articular and synovial response, and for this reason injections were omitted at various times in some of the animals in order to compare the degree of permanent change which had occurred. At a later date, when the arthritis had apparently reached a stationary phase, bacterial extract was again introduced into the joints and the intradermal and agglutination reactions were studied.

Intradermal injections of the bacterial extract were given all the rabbits in this series, after the second injection into the knee, and subsequently accompanying each injection into the knee, with results as shown on table 1. Eight animals that had not received the bacterial extract were used as controls for the intradermal reactions and, uniformly, the intradermal tests on these were negative. In order to exclude the factor of foreign protein sensitization from the culture mediums on which the organisms had been grown, four agar test tube slants were covered with saline solution and placed in the incubator for several hours. The saline extract of the mediums was then filtered through a Berkefeld filter, and a series of intra-

dermal reactions was run. These were all negative. To control the factor of chemical irritation in producing a pseudoreaction, lactic acid titrated to a p_H of 4.5 was injected intradermally into eight rabbits. These tests were also negative. An area of redness and induration of at least 1 cm. in diameter appearing at the site of inoculation within twenty-four hours and gradually fading after from forty-eight to seventy-two hours, leaving an area of brownish pigmentation, was considered a positive intradermal reaction. Frequently, there were minute papules within this area of redness, but on no occasion was there necrosis.

The characteristic reaction in the knee joints, following the introduction of the bacterial extract, appeared within twenty-four hours after the injection. The striking feature was the distention of the capsule by effusion, and the rather mild degree of peri-articular edema and induration accompanying this pronounced

TABLE 1.—Results in Rabbits Receiving Injections of Bacterial Extract Into the Right Knees and Saline Into the Left Knees*

Rabbit	Right Knee, Injections of Bacterial Extract	Joint Reaction		Type Reaction After 6th Injection	Positive Intradermal		Blood Serum Agglutination with Flexner Dysenteriae After 10th Injection	End-Result Reaction with Bacterial Extract Joint	Days Observation After Last Injections of Bacterial Extract	Left Knee, Saline Injections	End-Result, Saline Joints
		After (—) Injection	After (—) Days		After (—) Injection	After (—) Days					
5	10	3d	11	2+	7th	40	1:2,500	3+	200	10	Negative
6	8	3d	11	3	6th	33	1:2,500	4	290	7	Positive ^b
7	5	3d	11	3	....	..	.....	2	12	5	Negative
8	10	3d	11	2—	9th	51	1:1,280	3	290	10	Negative
13	9	3d	10	2+	7th	34	1:2,500	3	290	9	Positive ^b
14	10	3d	10	2	7th	34	1:1,280	3	290	10	control Positive ^b
15	0	2d	8	4	6th	34	1:5,120	4	60	6	Negative
16	5	3d	11	2	4th	22	1:2,500	2+	61	5	Negative
73	10	1st	2	3	....	..	.....	4	139	10	Negative

* After a definite arthritic lesion existed in the right knee, these rabbits were given a single injection of bacterial extract in the normal left knee. A reaction appeared promptly in the left knee. In designating the degree of joint reaction numbers from 1 to 4 have been used. Number 1 signifies slight peri-articular infiltration. Number 2 signifies slight peri-articular infiltration and some intra-articular exudation. Numbers 3 and 4 signify relatively more marked peri-articular infiltration and intra-articular exudation.

synovial response. Forty-eight hours after the introduction of the extract, the peri-articular reaction had completely subsided, except a mild degree of capsular thickening as determined by palpation, but an excess of joint fluid persisted for days. In the latter part of the experiment when permanent intra-articular changes existed, as seen in the photographs, this joint effusion, likewise, became permanent. Synovial membrane thickening could be felt as a boggy tissue on either side of the patella. The amount of fluid in these joints gradually increased, so that on several occasions as much as 1.5 cc. was aspirated, and an equal volume still remained in the joint. On numerous aspirations, cultures of the joint fluids were made, and direct smears were examined both for organisms and for cellular content. These cultures were all negative, and no organisms were seen in the smears. The fluid was cloudy, viscid and clotted rapidly. Smears showed many leukocytes, approximately 80 per cent polymorphonuclears and 20 per cent lymphocytes. Chemical studies of four of these effusions showed a sugar content of from 97 to 143 mg. per hundred cubic centimeters, always a figure within 20 mg. of the blood sugar

done at the same time. A sufficient number of chemical studies were not made, however, to warrant any conclusions for comparison with the study of joint effusion in man by Allison and Fremont-Smith.⁷

During the forty-eight hours following each injection of bacterial extract, all of the rabbits limped and showed a definite tendency to avoid bearing weight on the right leg. After this initial period, there was no apparent pain, and the animals hopped about normally. All of this series developed deformities of the right knee joint after they had received from six to eight injections of the extract. This deformity consisted of a flexion contracture of from 10 to 20 degrees, mild genu valgum, dense, spindle-shaped enlargement of the joint and some muscle atrophy, verified by x-ray films. This typical deformity persisted permanently after all injections had been stopped, and did not cause any visible inconvenience to the animals. Several rabbits were observed for six months or more after the last injections into the knee joint, and then were killed. This series showed that a permanent lesion in the joint resulted from the repeated introduction, intra-articularly, of a bacterial extract.

SERIES II.—One cubic centimeter of a twenty-four hour agar growth of living *B. dysenteriae* Flexner organisms, suspended in saline solution, was injected into a knee joint of each of five rabbits. All showed reactions beginning twenty-four hours after injection consisting of a marked inflammation of the soft tissue extending from the midhigh region down to the ankle joint. In these rabbits the primary reaction partially subsided in from three to five days, leaving a slight degree of peri-articular thickening and a moderate amount of joint fluid. Rabbit 35 in this series did not show a residual lesion after five weeks. Another rabbit did not develop a lesion after two weeks, and twenty-two days later had a litter of nine rabbits, five of which she raised. Rabbit 26 had a persistent, mild, periarticular thickening for four weeks, then developed an inguinal abscess on the other side, and died forty-two days after the infection developed. Autopsy showed multiple abscesses of the lungs and liver, but no macroscopic abnormality of either knee joint. Culture of the inguinal abscess showed a small, pleomorphic, gram-positive bacillus which, unfortunately, failed to grow on subcultures. Rabbit 27 had a normal knee joint four weeks after the infection, but at this time developed a mild diarrhea which reappeared during a period of thirty-nine days. Simultaneously with the appearance of the diarrhea, a slight effusion into the previously infected joint was noted. This effusion persisted with a mild degree of peri-articular thickening. The course of this rabbit seemed most significant when compared with those of the other rabbits of this series and in series 1. With this exception, the other rabbits did not show any signs of a persistence of the dysentery infection, and, likewise, did not show any persistent synovial membrane lesion. Like the rabbits in series I, however, this rabbit had a recurring synovial response definitely associated with diarrhea, a sign of a persistent dysentery infection though the organisms were not recovered by cultures. Rabbit 28 ran a typical acute infection of the knee joint for five days, and slight thickening of the joint was noted until twenty-one days after its infection, when it was completely normal. Thirty-nine days after infection, the rabbit was killed and gross changes were not found in the infected joint. Table 2 shows the results in the rabbits in series II.

SERIES III.—Seven rabbits were given subcutaneous injections of the bacterial extract, from 1 to 3 cc. per injection, at intervals corresponding to those in series I. No reactions were noted in these animals, local, focal or general, though all of their joints were examined carefully. One of this series received an injection of bacterial

7. Allison, N., and Fremont-Smith, F.: *J. Bone & Joint Surg.* 8:758, 1926.

extract into the knee joint after the eighth subcutaneous injection, and twenty-four hours later had a mild degree of peri-articular thickening and a moderate joint effusion. This effusion lasted for eight days. The knee reaction was more marked than any reaction which occurred in series I following the first two injections. This series showed that the bacterial extract might be injected into rabbits without causing a reaction, but that following subcutaneous injections, the rabbits had become hypersensitive to the extract and a single intra-articular injection was then capable of producing an arthritis.

SERIES IV.—Three rabbits received eight injections of fresh horse serum, 1 cc. each, into the right knee joint, the interval between injections varying from five to seven days. In two, the third injection was followed by a severe peri-articular reaction with redness, induration and edema of the soft tissues extending from the midhigh region to the ankle joint. The third rabbit did not have a reaction until the fifth injection into the joint, when this joint reacted similarly to the other two. In marked contrast to series I, the reactions in this series completely subsided thirty-six hours after each injection. Positive intradermal reactions to horse serum were observed after the third injections into the first two rabbits, and after the fourth injection into the third rabbit, thirteen and twenty days respectively

TABLE 2.—Rabbits Having Received Viable Dysentery Bacilli Intra-Articularly

Rabbit	Knee Type Reaction†	Duration of Reaction of Knee	End-Result (—) Day	Agglutination Titer	Intradermal
25	1	10 days	Negative 80th	1:320	+ 12th day
26	2+	25 days	Slight reaction 39th	.....	+ 12th day
27*	2+	Persistent	2+ 95th day	1:640, 1:2,500	+ 12th day
28	2	25 days	Negative (?)	1:1,280	± 12th day
35	2	33 days	Negative (?)	.....	.....

* Chronic intestinal dysentery infection.

† The degree of joint reaction is designated by numbers 1 to 4. The joint reactions in this series were in no way as marked as in series 1.

after the initial injection. Though these rabbits received eight injections into the joints, permanent changes were not noted macroscopically or microscopically when autopsy was performed. In marked contrast to series I, in which after the initial reaction in the knee joint all subsequent reactions were progressively more severe, in this series, after the initial, moderately severe reaction, all subsequent reactions were less severe. This was true to such an extent that following the seventh injection of horse serum into the knee joint, no change was noted in the joints twenty-four hours later. An eighth introduction of the horse serum intra-articularly, did not cause a reaction, and the fluid injected was as readily absorbed as the saline solution in the control joints. Intradermal reactions with horse serum, performed immediately after the injections into the knee, showed a correspondingly lessened reaction following the initial severe reaction, but were persistently positive.

This series exhibited the characteristic signs of an anaphylactic response to a foreign protein, not associated with bacteria. The appearance of an anti-anaphylactic phase and the absence of a progressive lesion in the joint seems to differentiate between a foreign protein sensitization reaction, or anaphylaxis, and an allergic phenomena, that is, a sensitization response to the products of bacterial growth.

SERIES V.—One rabbit that received 1.5 cc. of bacterial extract intravenously had no reaction, either immediate or late. At intervals of from three to five days, a second rabbit received five intravenous injections of the bacterial extract in

increasing amounts, from 1 to 5 cc. Other than a mild diarrhea of one day's duration, probably attributable to diet, a reaction was not noted. This experiment showed that the bacterial extract used could be tolerated when given intravenously, and that the extract was neither highly toxic nor powerfully irritant.

SERIES VI.—Eight rabbits were given eight intra-articular injections of 1 cc. each into the knee at intervals of from three to six days. Tenth-normal lactic acid solution, titrated to a pH of 4.5 with a tenth-normal solution of sodium hydroxide, was injected. Seven rabbits in this series did not show any symptoms, and each injection was followed by almost immediate absorption of the fluid introduced. The eighth rabbit had a slight degree of peri-articular thickening about the knee joint following the second injection of acid, and a minimal capsular thickening persisted, though on subsequent injections of acid further reaction did not occur. These experiments were done to control the first series by a mild chemical irritant. The acidity of the solution was far below the normal alkalinity of the joint fluid. Lactic acid was used rather than some other acid because it is an organic substance found in the urine of rabbits in various conditions of exhaustion and disease.

SERIES VII.—On the assumption that the rabbits of series I might have developed a specific joint sensitization to the bacterial extract, seven rabbits were given intravenous injections of 1 cc. of a twenty-four hour growth of living *B. dysenteriae* Flexner organisms suspended in saline solution. Three of the seven rabbits had arthritic knees similar to those in series I; one had had viable organisms injected into the knee joint as was done in series II; one had received subcutaneous injections of the bacterial extract, and two had received intravenous injections of the bacterial extract. The seven rabbits appeared ill the day following the injection and had a slight diarrhea, but none showed lesions or symptoms forty-eight hours later. Reactions did not occur in any joints. These rabbits were observed for several weeks, and no late lesions were noted.

This experiment indicated that the earlier introduction of bacteria or a bacterial extract into a joint did not cause the localization or activation of a lesion in this joint when the same bacteria were introduced intravenously.

SERIES VIII.—Six rabbits from the series in which injections of lactic acid were given received further injections of 1 cc. of a two tenth-normal solution of lactic acid into the right knee joint. Within twenty-four hours all showed a mild periarticular thickening with a slight effusion in the knee joint. Three of the rabbits had received four injections of bacterial extract, at intervals from three to seven days, into the right elbow joints prior to the last injection of lactic acid. The periarticular thickening of the knees persisted for six weeks. At this time there was evidence of a knee lesion in only three of the rabbits, those having received injections into the elbows of bacterial extract. Two more injections of bacterial extract were given these three, and a mild, progressive reaction was noted in the right knee joints, characterized by a slight joint effusion, and a persistent capsular thickening. The joint trauma produced in this experiment by the injections of lactic acid seemed to localize the reaction accompanying repeated injections of bacterial extract in another joint, the elbow. But before arriving at definite conclusions, this experiment must be repeated on a larger series of animals. This apparent association of trauma and the formation of an arthritis was of great interest.

SERIES IX.—Thirty cubic centimeters of the bacterial extract was sealed in test tubes and immersed in a water-bath at 70 C. for one hour. This heated extract was then injected into the knee joints, and intradermally, in eight rabbits, five used previously in series I, one from series V, one from series VI and one from series III.

The rabbits from series I showed the same type of knee response as was seen when the unheated bacterial extract had been introduced, and, likewise, had positive intradermal reactions with the heated extract. The rabbit from series III, which had not received any injections of bacterial extract for two months, had a negative intradermal reaction. One rabbit that had received living dysentery organisms intravenously one month before, had a questionably positive reaction intradermally, as did also the rabbit from series VI. The last rabbit received intradermal injections of the unheated bacterial extract on other occasions, but had not had larger amounts of the extract. Of most interest, in this experiment, was the characteristic reaction which occurred in the rabbits in series I, demonstrating the fact that the bacterial extract had not been altered in its antigenic properties by heating.

The animals that received injections of bacterial extract were all given intradermal injections of unheated, heated to 70 C., and boiled bacterial extract. In the instances in which the unheated extract gave a positive reaction, that is, one larger than 1 cm. in diameter, a positive reaction also was obtained with both the heated and the boiled extract.

All of the rabbits in these experiments were followed at monthly intervals by roentgen examinations and weighing. White and red blood cells were studied in several rabbits, but because the normal daily variation in rabbits was as much as 100 per cent, this datum was not significant. Variations in temperature were also found to be both unreliable and dependent, on atmospheric conditions.

Blood serum agglutination studies were made on all of the rabbits (table 3). The antigen, for these reactions, was a saline suspension of a twenty-four hour agar slant growth of the original *B. dysenteriae* Flexner strain. Ten normal rabbits were used as controls. Two of the controls showed positive agglutination at a dilution of the serum up to 1:160, two up to 1:80, four up to 1:40 and two to 1:20. Of the rabbits that received parenteral injections of bacterial extract, only those having had intra-articular injections reached a serum agglutination titer of 1:1,280, and several of these went as high as 1:2,560. The rabbits that received subcutaneous or intravenous injections of bacterial extract had serum agglutination titers varying from 1:160 to 1:640. All the rabbits that received living dysentery organisms developed a titer of from 1:2,560 to 1:10,240. Of interest was the fact that only the rabbits that received intra-articular injections of the bacterial extract had serum agglutination titers above 1:640, excluding those that received living, dysentery organisms. All of the rabbits that had a titer of 1:1,280 or higher, showed positive intradermal reaction with the bacterial extract. Half of the animals with a titer of 1:640 had positive intradermal reactions with the bacterial extract, while none of the rabbits with a titer below 1:640 gave positive intradermal reactions with the bacterial extract.

PATHOLOGIC OBSERVATIONS

Autopsy was performed on ten of twelve rabbits and gross and microscopic examinations were made. Seven had received injections of bacterial extract intra-articularly; three, living dysentery organisms intra-articularly; one, horse serum intra-articularly, and one, lactic acid intra-articularly. Each rabbit on which autopsy was performed had previously shown changes characteristic of its respective series.

A. Rabbits that Had Received Intra-Articular Injections of Bacterial Extract.—Rabbit 1 received five subcutaneous injections of bacterial extract and then a single intra-articular injection, and was killed eight

days later. Macroscopically, there were no variations from the normal. Microscopically, a fairly marked synovial membrane hyperplasia was noted. The normally flattened synovial membrane cells had become cuboidal. The bone, cartilage and soft tissues did not show any abnormal changes.

Rabbit 7 received five intra-articular injections of bacterial extract over a period of thirty-three days, and was killed twelve days later. Repeated cultures of the joint fluid had been negative. The joints into which saline was injected did not show any macroscopic or microscopic changes. The joint into which bacterial extract had been injected had extreme synovial membrane reaction with macroscopic villus formation.

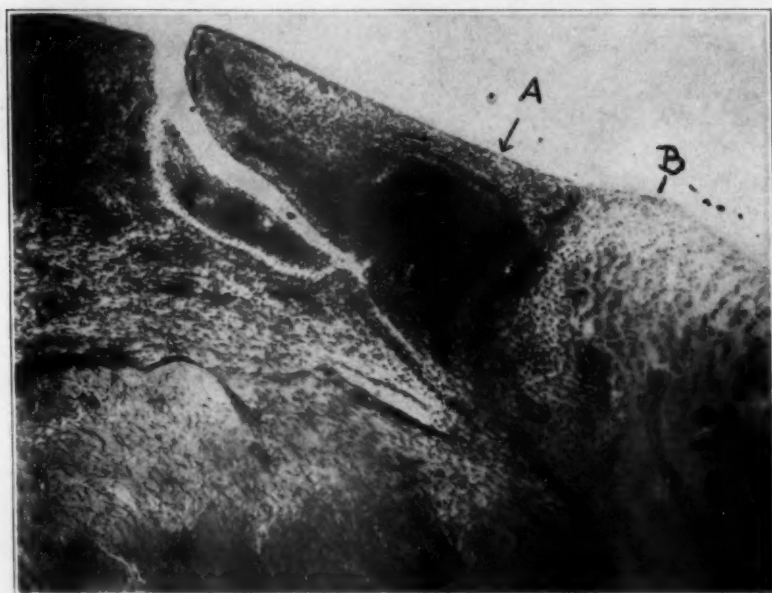


Fig. 1 (rabbit 7).—Right knee, junction of synovial membrane, ligaments and femoral articular cartilage showing infiltration and hyperplasia of synovial membrane (A), and beginning pannus formation (B); $\times 80$. Compare with figure 15.

The synovial cavity contained, approximately, 1 cc. of thick, viscid, yellowish, cloudy fluid. Two masses of new bone, in the form of small ridges, were found just anterior to the epicondyles and lateral to the patellar groove. Macroscopic cartilaginous changes were not seen. Microscopically, there was a striking picture of synovial membrane reaction, marked hyperplasia, cellular infiltration of the synovial membrane and subsynovial tissues, numerous masses of lymphocytic cells, and infiltration at the junction of the synovial membrane and ligamentous tissues with the articular cartilage. The articular cartilage had a ragged surface with beginning pannus of connective tissue extending

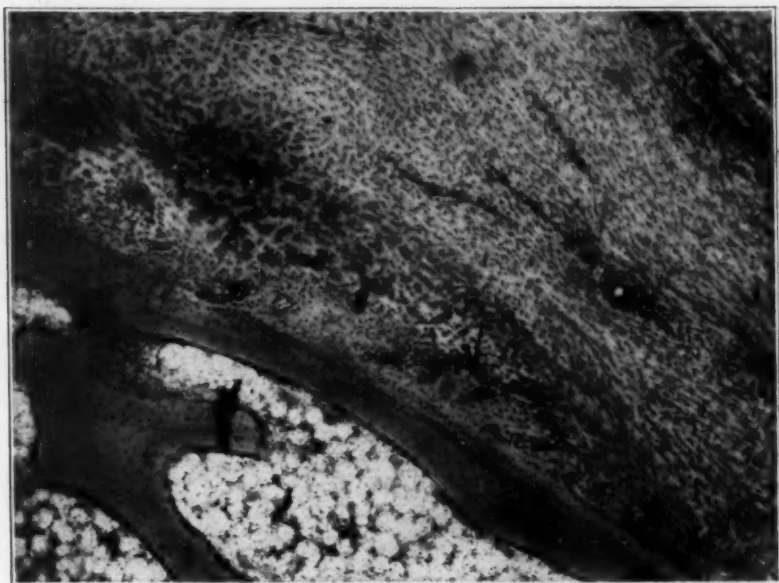


Fig. 2 (rabbit 7).—Internal condyle of right knee joint showing new bone and active periosteum (*B*) at site of ligamentous attachment to bone; $\times 80$.

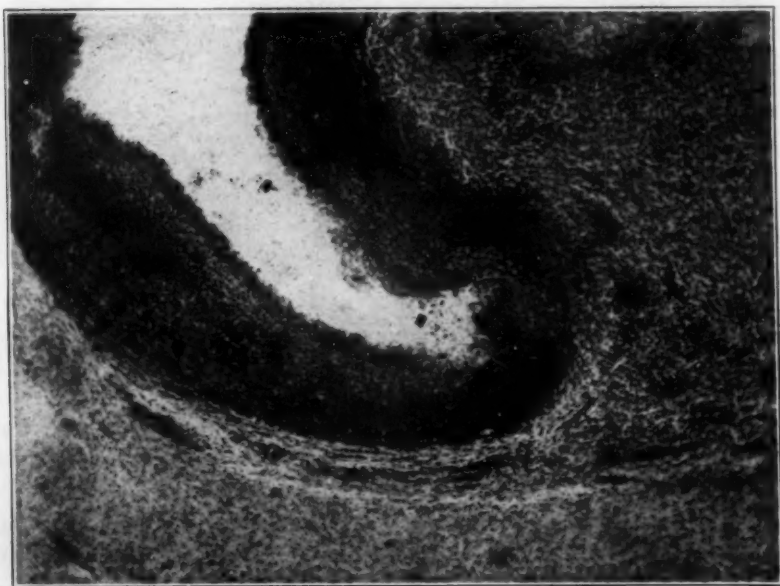


Fig. 3 (rabbit 7).—Posterior synovial cavity of right knee joint. Marked synovial membrane hyperplasia and some lymphocytic infiltration of subsynovial tissues is seen; $\times 80$. Compare with figure 13, showing chronic synovial membrane changes. Normally, the synovial membrane consists of one or two layers of flattened cells, mesenchymal in origin.

centrally over it. In the femoral depression between the epicondyles and the patellar groove new bone formation was noted with active periosteum and numerous young fibroblasts. No atrophy of the bone was seen. The chief changes consisted of a synovial membrane hyperplasia and a pannus formation (figs. 1 to 4).

Rabbit 16 received five intra-articular injections of bacterial extract over a period of twenty-eight days into the right knee joint, and an equal number of injections of saline into the left knee joint. The rabbit was killed sixty-four days after the last injections. Cultures of the joint fluid had been repeatedly negative. X-ray pictures showed an increase in the size of the right femoral condyle and a slight fuzziness

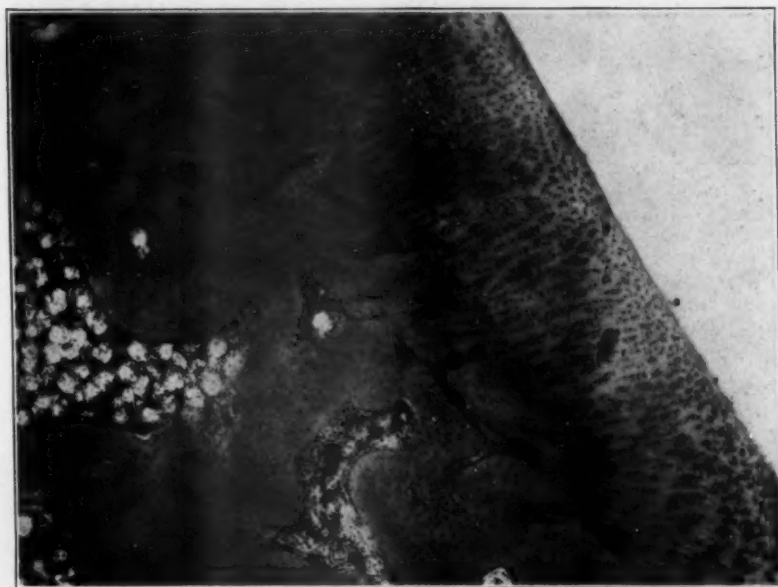


Fig. 4 (rabbit 7).—Articular cartilage with underlying bone of right knee joint. Cartilage surface is slightly ragged. There are no bone changes. The reaction has been primarily synovial as seen in figures 1 and 3. Compare with figure 11, showing bone atrophy associated with old lesion; $\times 80$.

of the articular surfaces. Gross examination of the specimens showed a normal left knee joint, but thickened and hypertrophied synovial membrane of the right knee joint with opaque, whitish masses extending over the condyles. Microscopically, there was synovial membrane hyperplasia with scattered areas of lymphocytic infiltration in the right knee only. Also in this joint, there was beginning pannus formation with slight cartilage destruction beneath the pannus.

Rabbit 15 received six intra-articular injections of bacterial extract over a period of thirty-three days, and injections of saline solution in

the left knee were done as controls. The rabbit was killed sixty-nine days after the last injections. Cultures of the fluid from the right knee joint had been negative. X-ray pictures showed a destructive process involving the cartilage of the right joint, distended joint capsule, and new bone formation at sites of ligamentous attachments. Macroscopically and microscopically, the left knee was normal. The right knee joint showed synovial membrane hyperplasia with numerous synovial tags, a few small areas of subsynovial lymphocytic

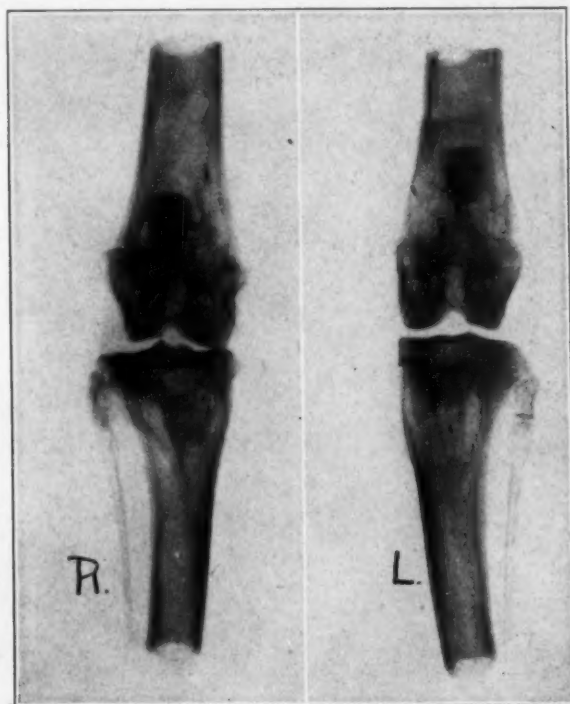


Fig. 5 (rabbit 15).—Fuzzy appearance of articular surfaces of right knee joint with synovial membrane infiltration shown by increased density of soft tissues. The rabbit received six intra-articular injections of bacterial extract and was killed sixty-nine days after the last injection. Left knee joint received equal number of injections of saline solution. Compare with figure 10, showing knee joint having reached a more advanced lesion.

infiltration, cartilage destruction with new bone formation and replacement of articular cartilage by a pannus of connective tissue (figs. 5, 6 and 7).

Rabbit 73 received ten intra-articular injections of bacterial extract into the right knee joint over a period of forty-four days, and simultaneous injections of saline solution into the left knee joint. The rabbit was

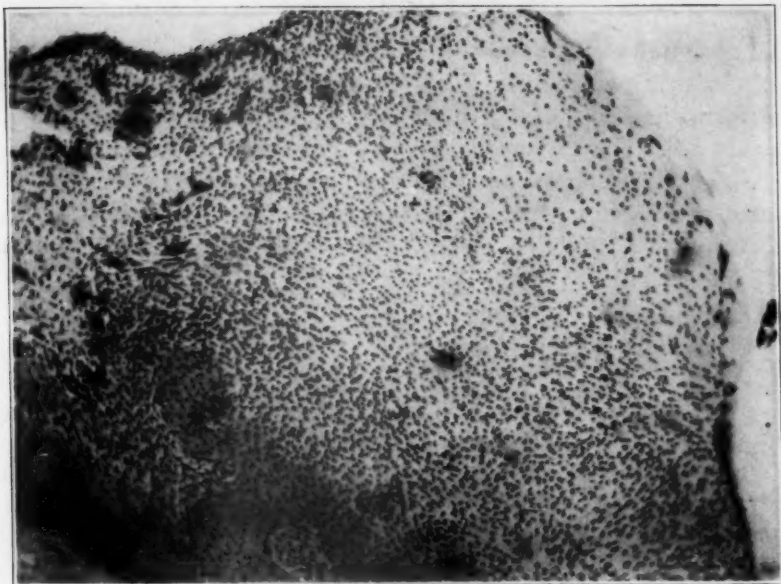


Fig. 6 (rabbit 15).—Right knee joint. Cartilage replacement by fibroblasts with new bone formation (*A*); area of articular surface at mesial border of internal femoral condyle; $\times 160$.



Fig. 7 (rabbit 15).—Right knee joint. Marked femoral cartilage replacement by fibroblasts with overlying connective tissue pannus (*A*); $\times 160$.

killed four and one-half months later. Cultures of the joint fluid had been persistently negative. Roentgen examination showed marked new bone formation, distended joint capsule and moderate valgus deformity of right knee. The left knee joint was normal. Macroscopic examination of the right knee showed an area of complete cartilage destruction with exposed raw bone, no normal, glistening cartilage, but whitish, opaque pannus extending over former site of cartilage. The synovial membrane and joint capsule were markedly hypertrophied, with formation of villi.



Fig. 8 (rabbit 73).—Valgus deformity of right knee joint, spindle-shaped enlargement and muscle atrophy above and below joint. This rabbit received ten intra-articular injections of bacterial extract in right knee joint and was killed four and one-half months later.

Microscopic examination showed atrophic bone trabeculae, remaining areas of cartilage poorly stained, and completely covered by a pannus of connective tissue. Beneath the pannus, the cartilaginous surface was ragged. New bone formation was seen over femoral condyles in atypical structure. The synovial membrane was markedly hyperplastic, but only occasional areas of infiltration were found. In areas of car-

tilage destruction, underlying bone was covered by a thin layer of dense connective tissue. New bone formation was most marked at the sites of ligamentous attachments (figs. 8, 9, 10, 11, 12 and 13).

B. Rabbits Received Intra-Articular Injections of Living Dysentery Organisms.—Living dysentery organisms were injected into the left

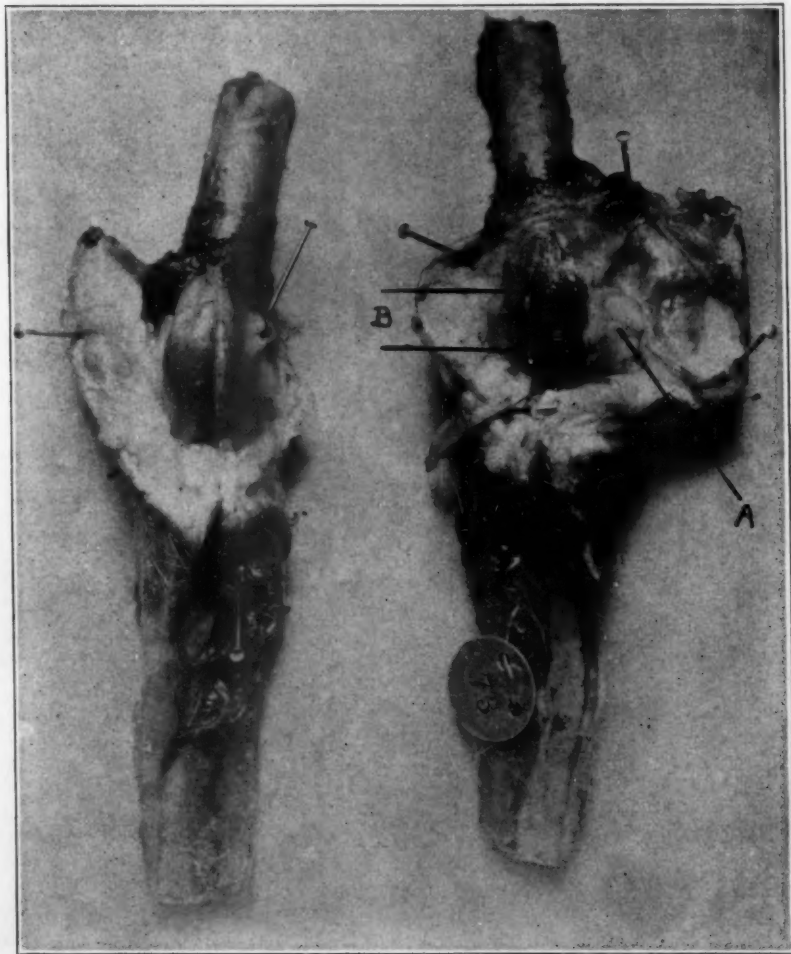


Fig. 9 (rabbit 73).—Right knee joint has metal tag. Area (A) shows synovial tags; area (B), complete destruction of femoral articular cartilage with exposed bone surface. Compare relative size of capsule and synovial tissues in two joints, left and right of same animal. Left knee received ten injections of saline solution; right knee, injections of bacterial extract.

knee joint of rabbit 35, and the animal was killed 142 days later. Roentgen or macroscopic changes were not found. Microscopic examina-

tion did not show any variation from the normal, with the exception of a thin layer of flattened cells extending over the cartilage surface of the left knee.

Living dysentery organisms were injected into the right knee joint of rabbit 26 and the animal died forty-one days later in an emaciated state. Autopsy showed multiple abscesses of the lungs and liver, and a large, left inguinal abscess from which a small, pleomorphic, gram-

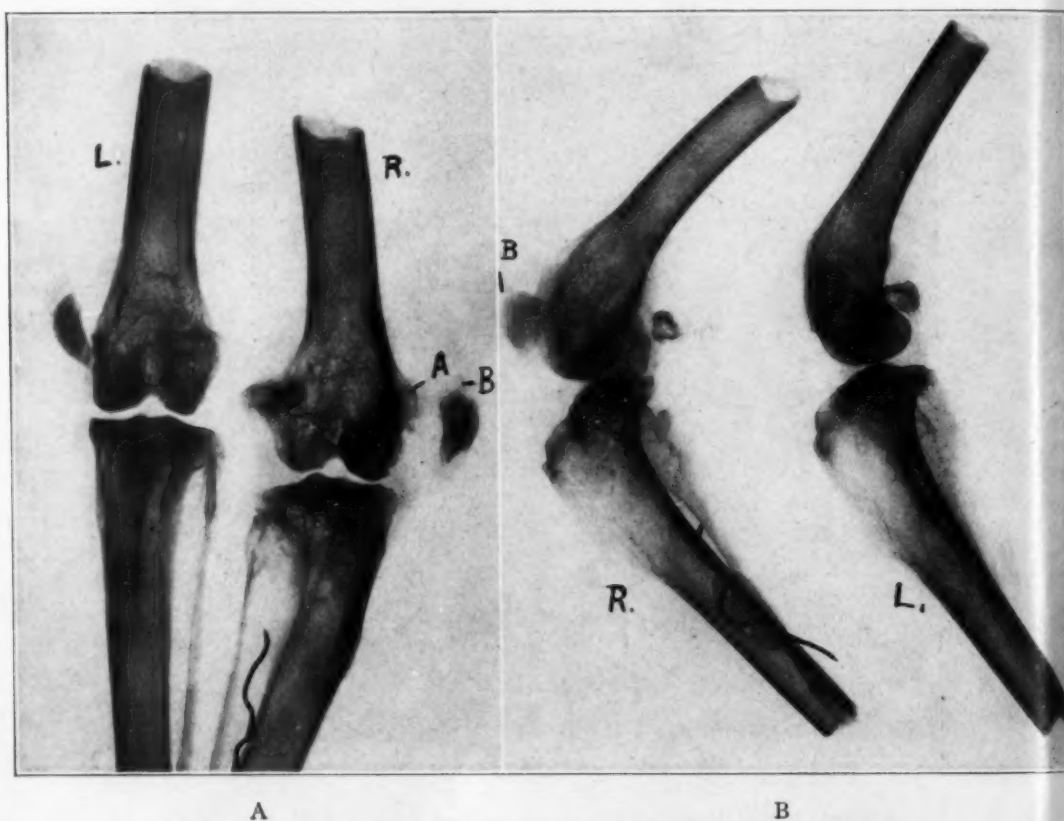


Fig. 10.—The anteroposterior and lateral view of knee joints of rabbit 73 at time of death. Wire seen in right leg, placed there post mortem. New bone formation most marked in region of right internal condyle (*A*) and osteophyte on patella (*B*). Bone atrophy in right knee joint can be seen. X-ray photographs made on same film with a single exposure. Increase in synovial and capsular tissues of right joint can be noted.

positive organism was cultured. Organism failed to grow on subcultures. The left knee joint was normal microscopically and macroscopically. The right knee joint did not show any gross changes, but, microscopically, there was a slight synovial membrane hyperplasia and

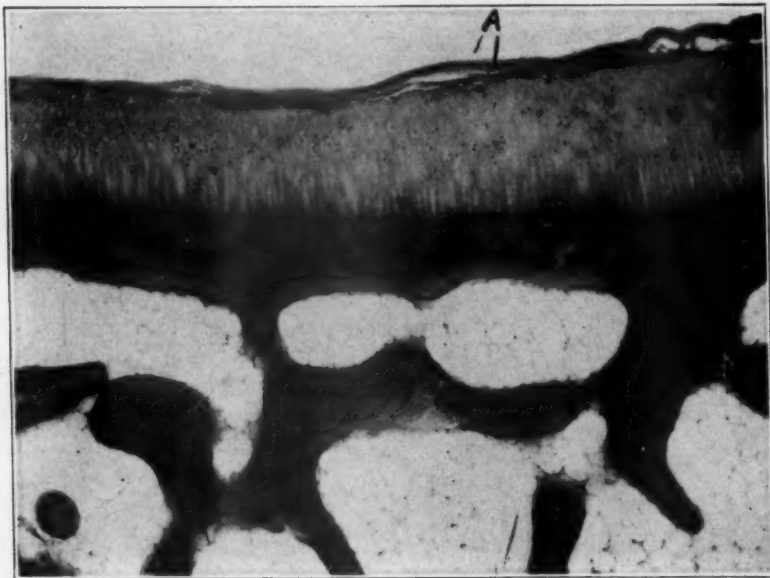


Fig. 11 (rabbit 73).—Cartilage and bone of right femoral articular surface. Pannus of connective tissue (*A*) with partial destruction of underlying cartilage is seen. Compare bone atrophy and inactivity of subcartilagenous bone with figure 4; $\times 80$.

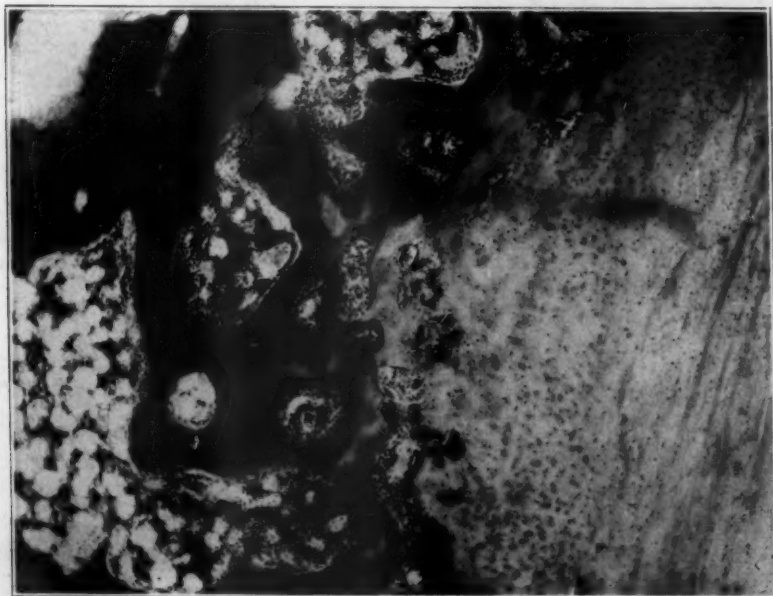


Fig. 12 (rabbit 73).—Internal condyle of right knee joint showing atypical new bone formation and active periosteum; $\times 80$.

infiltration, rather marked cartilage destruction over the internal condyle with pannus formation and a single adhesion between the pannus and the overlying synovial membrane. There was some patellar cartilage destruction with a pannus. No new bone formation was seen. These areas of pathologic significance were few and scattered, composing an entirely different picture from that described in the rabbits having received injections of bacterial extract (figs. 14 and 15).

C. Rabbit That Received Intra-Articular Injections of Horse Serum.—Rabbit 28 received eight injections of horse serum into the right knee joint over a period of fifty-three days, and was killed seventeen days

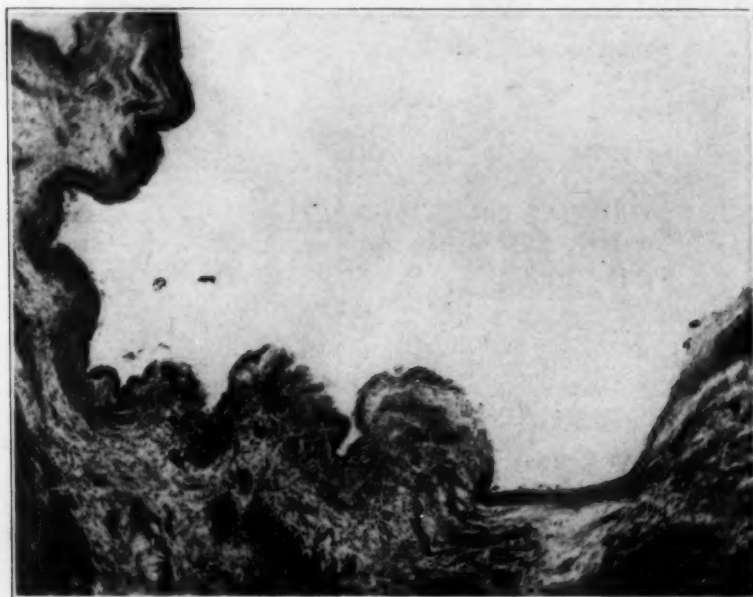


Fig. 13 (rabbit 73).—Right knee joint. Chronic synovial changes, consisting of villi and true synovial membrane hyperplasia as shown. Compare with figures 3 and 15; $\times 80$.

later. The results of the x-ray examination were negative. Visible gross changes were not found in the right knee joint other than a slight thickening of the synovial membrane. A few areas were seen in the microscopic examination where the femoral cartilage had a slightly ragged surface and a small overlying layer of exudate. A few scattered areas of synovial membrane infiltration and hyperplasia were found. No new bone formation, no cartilage destruction and no synovial membrane hyperplasia of significance was seen (fig. 16).

D. Rabbit That Received Intra-Articular Injections of Lactic Acid.—Rabbit 23 received eight injections of lactic acid into the right knee



Fig. 14 (rabbit 26).—Viable organisms injected into this joint. No macroscopic changes. Microscopic examination showed this single adhesion between synovial membrane and cartilage of femur (*A*) and single area of superficial invasion of femoral articular cartilage by fibroblasts; $\times 160$. Compare with figure 15 of left joint of this rabbit. The dark area is an artefact.

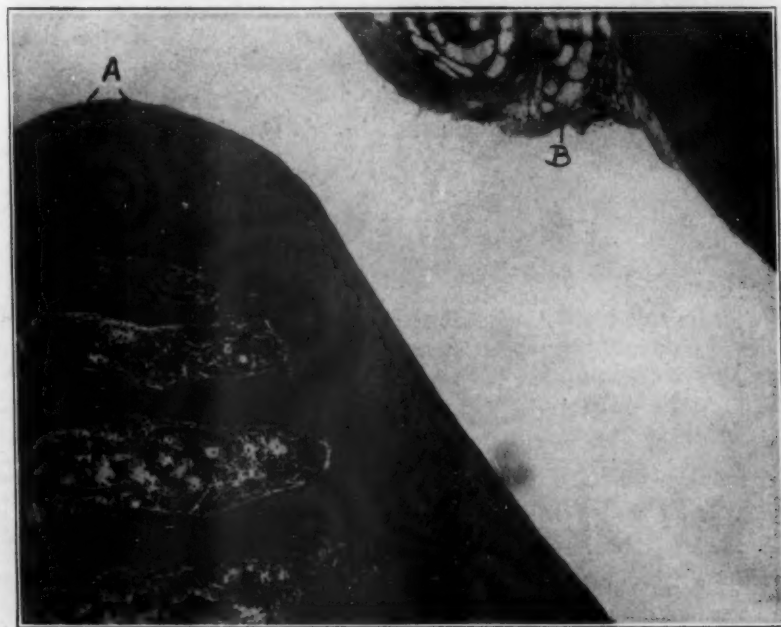


Fig. 15 (rabbit 26).—Left knee joint. Normal joint. Area (*A*), junction of femoral articular cartilage and synovial membrane, and area (*B*), synovial membrane, are shown for comparison with accompanying photomicrographs; $\times 80$.

joint over a period of forty-eight days, and was killed eight days later. The results of the x-ray examinations were negative. Macroscopically, the cartilage of the right knee joint appeared cloudy and dull. Joint effusion was not present. Microscopically, a picture of superficial cartilage necrosis was seen. The superficial layers of the cartilage did not show any nuclei, and these layers formed a smooth, uniform area over the deeper, normal cartilage. No synovial membrane, capsular or bony changes were found (fig. 17).



Fig. 16 (rabbit 28).—*B. dysenteriae* organisms injected into this joint. Only changes found were slight exudate on articular cartilage surface (A); no cartilage damage and no bone atrophy; $\times 80$.

COMMENT

A monarticular arthritis was produced in rabbits by the injection of an extract of *B. dysenteriae* Flexner, simulating the proliferative or toxic type of arthritis in man. Both the arthritis of man and the experimental one are characterized by a primary synovial membrane reaction, then cartilage destruction with late bony changes. Macroscopically and microscopically, these pathologic changes in man and as experimentally produced in rabbits bore a striking resemblance, as has been shown.

The experimental lesions were produced by repeated intra-articular injections of a Berkefeld filtrate of a bacterial suspension in physiologic sodium chloride solution which had remained at 37 C. for fourteen days. This filtrate contained bacterial products, the result of autolysis and saline extraction of living *B. dysenteriae* Flexner organisms. No attempt was made to separate the various elements composing this filtrate, as the filtrate represented, at least partially, the products of bacterial growth and destruction. It has been shown by repeated intravenous injections that the extract was not highly toxic when introduced by that route. Likewise, by varying the acidity and alkalinity of the filtrate, this factor has been eliminated as the causative agent in the



Fig. 17 (rabbit 23).—Superficial cartilage necrosis of femoral articular surface; the superficial cartilage cells did not stain; $\times 80$. This rabbit received eight intra-articular injections of lactic acid.

production of the lesions, contrary to the observations of Seeliger.⁸ The repeated parenteral introduction of the bacterial extract was accompanied by two types of reaction: an antibody reaction, characterized by the formation of specific agglutinins, and an allergic or altered tissue response, characterized by a gradually increasing intra-articular tissue reaction. When suspensions of living *B. dysenteriae* Flexner organisms were injected intravenously into animals previously treated with the filtrate, signs of infection did not appear.

8. Seeliger: Fünfzigste Tagung der deutschen Gesellschaft für Chirurgie, Berlin, 1926.

Subcutaneous injection of bacterial extract did not cause any lesions, though repeated frequently. These animals, however, became sensitized to the extract. With one exception, the initial intra-articular injection of the bacterial extract did not produce any lesion. If, however, the extract was injected repeatedly into the same joint, or a single intra-articular injection was made into an animal having previously received subcutaneous injections, a marked arthritis resulted. Continued intra-articular injections were associated with a definitely progressive arthritis. Heating the bacterial extract to 70 C. for one hour, or boiling it for ten minutes, did not destroy its antigenic properties. In rabbits that received mild joint trauma by the injection of lactic acid, subsequent repeated intra-articular injections of the bacterial extract in another joint produced a mild inflammatory joint lesion in the joint which had been traumatized. The absence of joint reactions following primary intra-articular injection of the bacterial extract, the increasingly severe reaction following repeated intra-articular injections of the extract, and the failure of the animals to become anti-anaphylactic as the horse serum series did, seems to indicate that this inflammatory reaction was an allergic phenomenon, and neither a toxic nor an anaphylactic reaction. Intradermal reactions, 1 cm. or more in diameter, ran parallel courses with the joint reactions, though the intradermal reactions became positive at a time when the joint reactions had existed for two or more injections of bacterial extract. In the horse serum series the articular and the intradermal reactions also ran parallel courses, both subsiding during an anti-anaphylactic phase.

Faber⁹ and Herry,¹⁰ working with streptococci, reported that joints of rabbits could be sensitized to dead bacteria or bacterial products so that intravenous injections of the same strain of bacteria, following a period of one to two weeks, resulted in a localization of the bacteria in the previously treated joints. Swift and Boots¹¹ were unable to confirm these experiments. Although I have used an entirely different organism, and one not associated with acute arthritis, the results indicate a sensitization phenomenon which resembles, in manner of production, the arthritis of Faber and Herry, but differs widely in the nature of the organisms and the resulting type of arthritis. A laboratory strain of organisms, of apparently low virulence, has been used in the production of a bacterial extract which caused joint lesions on repeated injections. That these lesions appeared only following repeated injections of the extract seems to indicate that a condition of joint sensitization

9. Faber, H. K.: *J. Exper. Med.* **22**:615, 1915.

10. Herry: *Bull. de l'Acad. roy. de méd. de Belgique* **28**:76, 1914.

11. Swift, H. F., and Boots, R. H.: *J. Exper. Med.* **38**:573, 1923.

occurred as a local manifestation of sensitization, or allergy. Birkhaug,¹² in a recent report, stated that a bacterial filtrate from a culture of streptococci isolated from the blood stream of a patient having acute rheumatic fever produced a polyarthritis in rabbits after repeated, increasing intravenous and subcutaneous injections, and produced a polyarthritis in the author himself after a single intra-articular injection. This organism was also a virulent one, and one associated with acute polyarthritis on injection into rabbits, but, as Birkhaug suggested, the production of arthritis by repeated filtrate injections indicated an allergic phenomenon to the bacterial toxin. Whether or not the bacterial toxin was the causative factor in the production of the allergic state may be questioned.

Zinsser and Grinnell¹³ have recently produced a state of allergy in guinea-pigs by repeated injections of a pneumococcic autolysate. That the allergic state to bacteria may be induced in animals by the introduction of bacterial products or products of the bacterial bodies seems to be an established fact.

In the reports on bacillary dysentery epidemics, already mentioned, from 1 to 3 per cent of the patients developed arthritis, usually mono-articular, but often polyarticular, in which no organisms were found either by smears or by cultures of the joint fluids. Of interest was the time when these arthritides appeared, from twelve to twenty days after the onset of the intestinal symptoms, or later, a stage of the intestinal infection when intestinal signs and symptoms had usually disappeared. If a soluble toxin formed by the bacteria or a substance released on the destruction of the bacteria *in vivo* was the etiologic factor, would not this delayed appearance of the joint lesions be difficult to explain on any grounds other than as a sensitization reaction? The sensitizing substance, in this case the dysentery organisms or their products, was still present in the patients. Though the patients had developed immunity to the infection, evidenced by their convalescence, the joint lesions appeared as manifestations of local allergic reactions to this existing sensitizing substance. Dorst, Wherry and others have isolated organisms from the intestinal tract of arthritides which when injected as vaccines produced exacerbations of the arthritic lesions. May one deduce from the foregoing that, though vaccines may aid in the overcoming of foci of infection, by their introduction they may likewise aggravate the arthritic lesions by producing focal allergic reactions?

I have not attempted to establish bacillary dysentery infections as the etiologic factor in the production of all of the so-called proliferative

12. Birkhaug, K. E.: *Proc. Soc. Exper. Biol. & Med.* **24**:541, 1927; *J. Infect. Dis.* **40**: 549 (May) 1927.

13. Zinsser, H., and Grinnell, F. B.: *J. Bact.* **14**:301, 1927.

or toxic arthritides. These arthritides may be, however, local manifestations of a generalized state of allergy dependent on one of many bacterial infections. The evanescent and acute arthritides of acute rheumatic fever may have a similar etiology, but have intentionally been omitted from consideration in this paper.

Further studies are planned on the production of an arthritis by the localization of allergic reactions by producing joint trauma. The series of three rabbits, already reported, seems most significant in explaining the mechanism of this localization in allergic individuals.

CONCLUSIONS

1. An experimental arthritis simulating the proliferative arthritis of man may be produced in rabbits by the repeated injection of a bacterial extract.
2. This experimental arthritis appears to be a local allergic manifestation of a generalized state of allergy to a specific bacterium or bacterial extract.
3. The dysentery arthritides, and the exacerbations of chronic arthritides accompanying vaccine therapy, suggest that proliferative arthritis in man is also a local allergic manifestation of a bacterial infection.
4. That the site of infection in arthritis may be in the intestinal tract is indicated by a study of cases and by experimental data.

THE IMPAIRMENT OF CIRCULATION IN THE
VARICOSE EXTREMITY *

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While varicose veins may occur in various parts of the body, the superficial venous system of the lower extremity is of greatest clinical interest. The anatomy of these veins points out forcibly the unfavorable situation of the great and small saphenous veins between the skin and the superficial fascia. The number and distribution of valves,¹ their origin and development,² the anastomoses between the great and small saphenous vein and the communications between the superficial and deep venous system³ have all been extensively and repeatedly studied. Large variations in the course of the saphenous veins and the frequent appearance of accessory veins at unexpected sites would indicate an adaptation of man to changes of posture. In this respect, the varying course of the small saphenous vein, which is the main superficial venous channel in lower animals, has been thoroughly studied and emphasized by Kosinski.³

The histology of the veins has been carefully studied by many investigators.⁴ The endothelial lining is covered by a layer of transparent ground substances in which a sharply outlined elastic membrane, a more or less great amount of smooth muscle fibers of longitudinal, oblique and circular direction and, finally, a layer of adventitia are present. During the progress of varicose veins, the increasing pressure

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1. Hesse, R. W., and Schaak, W.: Die Klappenverhältnisse der Oberschenkelvene und der Vena saphena magna, *Virchows Arch. f. path. Anat.* **205**:145 (July) 1911.

2. Kampmeier, O. F., and Birch, Carroll La Fleur: The Origin and Development of the Venous Valves with Particular Reference to the Saphenous Distribution, *Am. J. Anat.* **38**:452 (Jan.) 1927.

3. Kosinski, C. H.: Observations on the Superficial Venous System of the Lower Extremity, *J. Anat.* **60**:131 (Jan.) 1926.

4. Literature in Nobl, G.: *Der variköse Symptomkomplex*, ed. 2, Berlin and Vienna, Urban and Schwarzenberg, 1918.



Fig. 1.—Hypertrophy of the saphenous vein. The vein is almost arterialized. Hypertrophy of all its layers has occurred. The increase in width of both intima and media should be noted.



Fig. 2.—Dilatation of the wall of a vein. Fibrous tissue replaces the muscular element. At certain points the media disappears entirely. The intima is hypertrophic.

tends to separate the muscle fibers, which respond first with a hypertrophy of the wall so often seen during high saphenous ligations (fig. 1). Later, the hypertrophy gives way to dilatation with a decrease of muscular and elastic elements. Their place is taken by a thick fibrotic connective tissue (fig. 2). The vulnerable intima, round cell infiltrations, thromboses, endophlebitides and periphlebitides result in dilated, rigid tubes with sacculations at the inpour of tributaries and with valves



Fig. 3.—Direct determination of venous pressure in varicose vein. The graduated tube, filled with physiologic solution of sodium chloride, is raised until the fluid remains stationary. The distance between the fluid level and the height of the punctured vein gives the uncorrected venous pressure expressed in centimeters of water.

flopping helplessly as thin folds in the wide lumen. All these represent end stages and are morphologic expressions of disturbances in function which have long preceded the anatomic condition.

Only recently has interest been aroused in the disturbances of venous pressure. This pressure is normally influenced by capillary pressure, the suction action of the thorax, the hydrostatic pressure and the blood

volume.⁵ It has been measured by the indirect methods of Recklinghausen, Eyster and Hooker, and Sewall, while Moritz and Tabora⁶ have probably been the first clinicians to connect up a vein with a water manometer and take readings of direct pressure on the veins. The literature on venous pressure and its clinical application, especially to heart disease, has been summarized by Eyster.⁷ Quite recently, Meisen⁸ reported measurements of indirect pressure on varicose veins with an apparatus devised by Krogh.⁹

TABLE 1.—*The Effect of Various Measures on Venous Pressure of a Varicose Vein (The Trendelenburg Test Was Positive)*

Position of Leg	Pressure in Centimeters of Water	Percentual Decrease in Pressure as Compared to the Standing Position
Standing*	108	0
Standing with pasteboot	75	21
Standing with rubber stocking	88	20
Standing after saphenous ligation †	43	61
Two weeks later	96	11
Sitting ‡	96	36
Horizontal	19	83
Leg elevated 45 degrees	-9	108

* The entire weight was put on the extremity.

† Ligation was made just above the inner femoral condyle.

‡ Feet on the ground.

TABLE 2.—*Determinations of Venous Pressure in Varicose Veins in Various Positions**

Case	Standing	Sitting	Horizontal	Comment
1	108	69	19	
2	76	44	8	
3	210	..	65	
4	90	61	30	
5	†	†	180	Anastomoses between superficial and deep veins were blocked by thrombi
6	89	57	10	
7	85	61	12	
8	105	59	13	

* These figures are not corrected to heart level, as the actual pressure exerted on the wall of the vein was estimated. The determinations were made with Eyster's venous pressure apparatus (indirect method). The figures represent centimeters of water.

† The pressure could not be estimated as the Eyster apparatus only registers up to 300 cm. of water.

5. Bedford, D. E., and Wright, L.: Observations on the Venous Pressure in Normal Individuals, *Lancet* **2**:106 (July 19) 1924.

6. Moritz, H., and Tabora, P.: Ueber eine Methode beim Menschen den Druck exact zu bestimmen, *Deutsches Arch. f. klin. Med.* **98**:475, 1910.

7. Eyster, J. A. E.: Venous Pressure and its Clinical Applications, *Physiol. Rev.* **6**:281, 1926.

8. Meisen, V.: Injection Treatment of Varicose Veins and their Sequelae on Basis of Five Hundred Treated Cases, *Acta. chir. Scandinav.* **62**:17, 1927.

9. Krogh, A.: *The Anatomy and Physiology of Capillaries*, New Haven, Yale University Press, 1922.

PROCEDURE

At the varicose vein clinic of Northwestern University Medical School, a simple graduated glass tube with a long rubber extension served as a water manometer (fig. 3). This was filled with a sterile one half of 1 per cent solution of sodium citrate. After the air bubbles were carefully expelled an intravenous needle connected with the rubber tube was inserted into a prominent subcutaneous vein, and the tube was gradually raised until the fluid level remained stationary.

The distance between the fluid level and the site of venipuncture was the pressure expressed in centimeters of sodium citrate solution, practically equal to that of centimeters of water. Such data were accepted only when the Valsalva experiment (expiratory effort with the

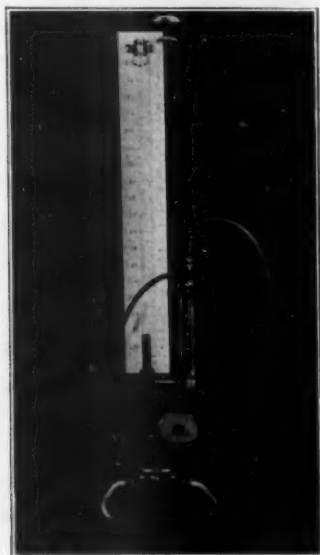


Fig. 4.—Eyster's venous pressure apparatus.

chest in inspiratory position and glottis closed) showed a definite rise in venous pressure, thus indicating that the manometer was unobstructed.

In one patient, the hydrostatic pressure as influenced by posture and therapeutic measures was repeatedly measured (table 1). The results indicate a high venous pressure on standing, which is reduced to normal by having the patient assume a horizontal position, but both the pasteboot and the rubber stocking reduce it to some extent (from 20 to 21 per cent). The immediate result of a saphenous ligation, undertaken 1 handwidth above the knee joint, was marked, but the pressure in the same vein two weeks later rose to more than double, illustrating the time honored experience that a simple ligation (Trendelenburg's operation) does not produce lasting results.

In ten other patients, venous pressure was estimated in various positions. The figures are given in table 2. While the normal venous pressure in the superficial venous system varies between 8 and 18 cm. of water in the erect position,¹⁰ these figures forcibly illustrate the insufficiency of valves with a reversed flow in the superficial veins. Clinically, this is easily demonstrable with the Trendelenburg test. The patient's varicosities are emptied when the leg is elevated. Next, the origin of the long saphenous vein below Poupart's ligament is compressed, and the patient is asked to stand up. The veins remain empty but fill up with a gush of blood from above when the compression is relieved.

Of more practical importance is the test for patency and sucking action of the deep venous circulation. If the patient stands up, his superficial veins visibly dilate. Next, a blood pressure cuff is applied to the thigh and inflated sufficiently to compress the superficial veins. The patient is now asked to walk to and fro in the room, during which time the varices diminish in size. To evaluate the diminution in size, the pressure cuff is suddenly relaxed and the veins fill up again from above. This test, first described by Perthes,¹¹ demonstrates a flow from the superficial into the deep veins into which the blood is sucked by muscular action. If the valves between the superficial and the deep veins are also incompetent, a back flow results. This can be demonstrated by a sudden filling of the saphenous veins in spite of compression of the saphenous trunk on the thigh.

Finally, if after compression the veins fill up slowly from below and do not dilate more after the pressure is relieved, the test is negative and all valves are competent.

It is easy to demonstrate either with the citrate manometer or with Eyster's venous pressure apparatus (fig. 4) that outside of the postural influence constricting garters will increase venous pressure.

Determinations with this capsule method of Eyster are not easy, because it is difficult to estimate the end-point, that is, the amount of pressure necessary to collapse the vein. Our readings, however, check within from 5 to 6 cm. of water with the direct determinations, and as in varicose veins the fluctuations in pressure are great, the method is useful and is serving us in our present work.

The suction action of the thorax and the big abdominal veins can be demonstrated to the naked eye in patients with large varicosities close to Poupart's ligament if the patients are brought to a semirecumbent position and asked to breathe deeply. The Valsalva experiment (forceful

10. Barach, J. H., and Marks, W. L.: Effect of Changes in Posture without Active Muscular Exertion on the Arterial and Venous Pressure, *Arch. Int. Med.* **11**:485 (May) 1913.

11. Perthes, G.: Personal communication to the author.

expiration in inspiratory position with closed glottis) always shows an increase in venous pressure. Such respiratory fluctuations do not occur below the knee.

CARBON DIOXIDE AND OXYGEN CONTENT OF THE BLOOD IN
VARICOSE VEINS

The increased pressure in varicose veins must result in stagnation of the blood, with changes in blood chemistry. Hippocrates stated that bile or mucus is present in hemorrhoidal nodes, and Ambroise Paré said that the blood in varicose veins was melancholic. The stasis produced in a normal vein leads to dehydration and increase in plasma proteins. The amount of fibrin, globulin and albumin is increased, however, to a greater extent than the dehydration could explain, so that an increased cell permeability for proteins is assumed by Plass and Rourke.¹² In order to determine the impairment of inner respiration, we determined the carbon dioxide content of the blood in a varicose vein and compared it with the carbon dioxide content of the cubital vein of the same patient (table 3). There is a definite increase in the carbon dioxide content of the blood in varicose veins, which would indicate that the carbon dioxide content of the tissues is even higher. In order to determine whether the carbon dioxide content is higher in the lower extremity than in the upper extremity in normal persons, seven patients without any varicosities were selected. Table 4 would indicate that in the normal saphenous vein the carbon dioxide content is not higher than in the cubital vein.

In another series, both the carbon dioxide and the oxygen content of blood from cubital and varicose veins were compared (table 5). The bloods were drawn over mercury, the apparatus and method described by Austin¹³ being used. The apparatus used for analysis was that of Van Slyke and Niel,¹⁴ and the manometric apparatus was used. A uniform increase in carbon dioxide and decrease of oxygen content was noted in the blood from varicose veins. In two instances the difference in oxygen content amounted to 8.95 per cent, whereas in others, smaller but always definite differences were found. A garter applied for fifteen minutes markedly diminished the oxygen content of the varicose vein (table 6).

12. Plass, E. D., and Rourke, M. D.: The Effect of Venous Stasis on the Proteins of the Blood Plasma and on the Rate of Sedimentation of the Red Blood Corpuscles, *J. Lab. & Clin. Med.* **12**:735 (May) 1927.

13. Austin, A. H., and others: Studies of Gas and Electrolyte Equilibria in Blood, *J. Biol. Chem.* **54**:126, 1922.

14. Van Slyke, D. D., and Niel, James: The Determinations of Gases in Blood and Other Solutions by Vacuum Extraction and Manometric Measurement, *J. Biol. Chem.* **61**:523, 1924.

TABLE 3.—Carbon Dioxide Content of Cubital and Saphenous Veins Expressed in Per Cent by Volume

Case	Carbon Dioxide in Cubital Vein	Carbon Dioxide in Varicose Vein	
1	55.8	57.1	
2	46.6	49.4	
3	54.0	59.2	
4	50.1	64.0	
5	50.7	59.1	High pressure in the vein
6	51.8	52.4	Poor arterial circulation
7	52.7	57.6	
8	53.0	58.9	
9	55.8	60.8	
10	55.8	58.7	High venous pressure
11	54.8	57.8	
12	54.8	58.7	
13	52.8	57.6	
14	53.2	58.1	Varicose veins, edema
15	53.2	59.2	
16	55.1	58.9	
Average figures	54.0	57.9	

TABLE 4.—Carbon Dioxide Content of Cubital and Saphenous Veins in Normal Persons *

Number	Carbon Dioxide in Cubital Vein	Carbon Dioxide in Saphenous Vein
1.....	60.1	60.0
2.....	58.9	60.4
3.....	59.2	58.9
4.....	61.4	60.9
5.....	62.0	61.5
6.....	59.9	59.7
7.....	60.4	61.1
Average figures	60.27	60.35

* Expressed in per cent by volume.

TABLE 5.—Difference of Carbon Dioxide and Oxygen Content of Cubital and Varicose Veins *

Case	Carbon Dioxide in Cubital Vein	Carbon Dioxide in Varicose Vein	Difference	Oxygen in Cubital Vein	Oxygen in Varicose Vein	Difference
1.....	50.16	51.44	1.28	10.77	7.37	3.40
2.....	54.23	54.33	0.10	10.71	8.91	1.80
3.....	45.49	45.76	0.27	13.35	10.66	2.69
4.....	48.44	49.98	1.54	11.80	9.73	2.04
5.....	45.70	50.09	4.39	15.12	6.17	8.95
6.....	56.87	59.38	2.51	12.44	3.49	8.95
7.....	51.91	56.36	4.45	16.89	10.87	6.02
Average figures...	50.40	52.47	2.07	13.01	8.17	4.84

* Expressed in per cent by volume.

This anoxemia obviously disturbs tissue respiration. The partial asphyxia may well explain the increased cell permeability, the slow healing tendency of wounds and the chronicity of ulcers. The increase in protein content both in venous blood and in lymph¹³ must have a bearing on the frequent observation of venous thrombosis and lymphatic obstruction in persons with varicose veins.

The lack of oxygen, the retention of carbon dioxide and other waste products, such as lactic acid,¹⁵ explain the complications seen in varicose veins, such as the chronic ulcer, the scaly, atrophic skin leading to varicose eczema and the periosteal changes. There is no need to assume trophic nerve disturbances, which have never been proved satisfactorily.

TESTS OF ARTERIAL CIRCULATION

Arteriosclerotic and diabetic gangrene and particularly thrombo-angiitis obliterans are often associated with dilated or even inflamed veins. It

TABLE 6.—Effect of Constricting Garter on Venous Pressure, Carbon Dioxide and Oxygen Content *

Case	Pressure	Carbon Dioxide	Oxygen	Hemoglobin
1 Without garter....	105	49.07	9.98	14.76 per 100 cc. 95%
With garter.....	130	49.35	6.46	14.76 per 100 cc.
2 Without garter....	89	42.00	13.62	13.23 per 100 cc. 78.7%
With garter.....	118	48.30	6.00	13.23 per 100 cc.

* A rubber garter was applied above the knee for fifteen minutes, the patient remaining in the standing position. The pressure is expressed in centimeters of water, and carbon dioxide and oxygen in per cent by volume. The hemoglobin was determined to test for possible dehydration.

is important to recognize the early cases and not mistake intermittent claudication for the cramps of the patient with varicose veins. The adequacy of arterial circulation ought to be tested in every person with varicose veins before treatment is instituted.

Pachon's oscillometer has proved of definite diagnostic and prognostic value in arterial occlusion.¹⁶ The instrument, however, cannot be used in daily practice. Sir Thomas Lewis,¹⁷ following the original observation of Eppinger, made a detailed study of the skin response to histamine. In our clinic the histamine test has been applied in all cases of varicose veins suspected of poor arterial flow, and a surprising number of abnormalities were found.

15. Wildegans, H.: Zur Entstehung der Thrombose, Arch. f. klin. Chir. **51**: 592 (April 23) 1927.

16. Silbert, S., and Samuels, S. S.: Thrombo-angiitis Obliterans: Prognostic Value of the Oscillometer, J. A. M. A. **90**:831 (March 17) 1928.

17. Lewis, Thomas: The Blood Vessels of the Human Skin and their Responses, London, Shaw and Sons, 1927.

If a 1:1,000 solution of histamine acid phosphate in physiologic solution of sodium chloride is applied with a medicine dropper to the skin, and six or seven punctures with a fine hypodermic needle are made through it, within a few minutes the "triple response" as described by Lewis¹⁷ can be observed. This consists of a small purple-red area, followed by a wheal and surrounded by a red flare around the puncture. This is the response of a normal person. The degree of the flare and the latent period of its appearance are the points to be observed and recorded (fig. 5). The flare is caused by the dilatation of the small arterioles and is the result of a local nervous reflex. It appears imme-

Reactions

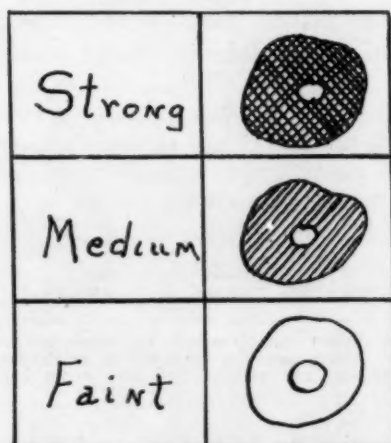


Fig. 5.—Reactions to injections of histamine in persons with varicose veins. The reaction was considered positive when a red flare appeared around the site of the injection. The reaction normally appears in two and one-half minutes.

diately after section of the peripheral nerve supplying the part, but not later, when nerve degeneration has extended to the point stimulated.¹⁷ The clinical application of this physiologic observation has been reported by Starr,¹⁸ who noticed delayed or absent reactions in arteriosclerotic or diabetic patients. Starr assumed that absence of histamine reaction means an arterial occlusion of some degree and advocated it as a test of circulation.

The histamine flares were usually elicited above the knee, just below the knee, at the middle third of the leg, above the ankle and occasionally at the base of the toes. Observations were made at two and a half, five,

18. Starr, Isaac, Jr.: Change in the Reaction of the Skin to Histamine, *J. A. M. A.* 90:2092 (June 30) 1928.

TABLE 7.—Histamine Reactions at the Ankle

Time	Number of Cases	Per Cent
2.5 minutes.....	3	10
5 minutes.....	6	20
10 minutes.....	5	16.6
15 minutes.....	3	10
No reaction.....	18	43.3

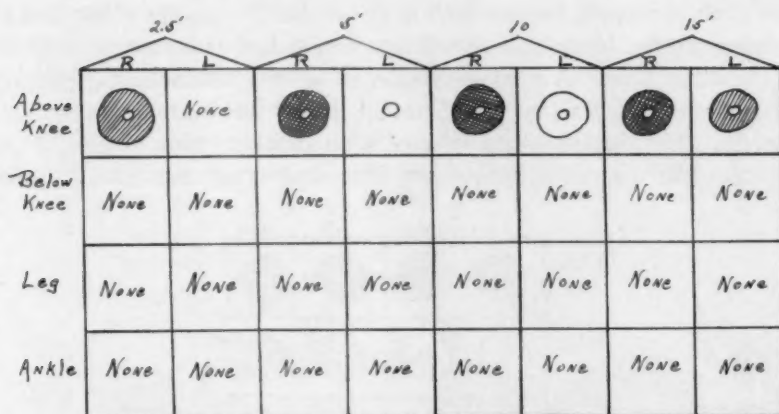


Fig. 6.—Results of histamine test in a night watchman, aged 47, with threatening arteriosclerotic gangrene. There was no palpable pulsation in the left dorsalis pedis and posterior tibial arteries. Two weeks following this test, the left fourth toe became cyanotic, later turning black. The patient was sent to the hospital. In this figure and in figures 7, 8, 9, 10 and 11, the numbers at the top indicate minutes.

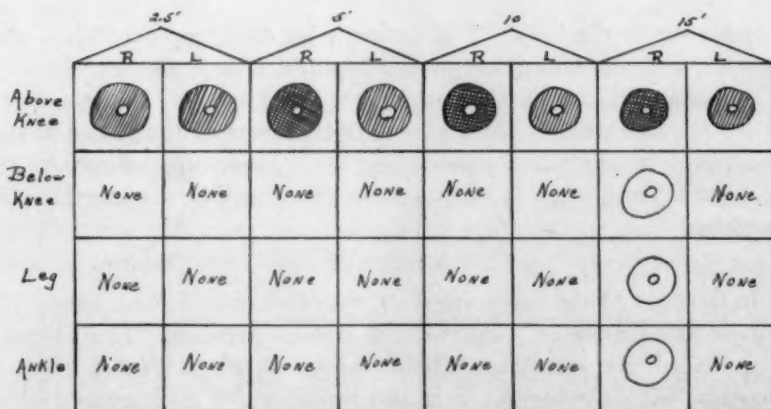


Fig. 7.—Results of histamine test made six weeks following the ligation of the left popliteal vein, after which the cyanosis of the left fourth toe disappeared.

ten and fifteen minutes. If there is a question as to the normal response above the knee, a histamine flare is produced on the arm in order to rule out a general refractory state of the vessels to the drug. A delayed or absent flare on the leg in the presence of a normal reaction elsewhere has been interpreted as an impairment of arterial flow.

Of thirty patients with varicose veins, approximately 50 per cent showed an abnormal reaction (table 7). Nine of ten healthy young persons with normal urine and normal blood pressure showed a normal response; the tenth person had a severe bruise on the thigh and the peripheral pulse in the side tested was diminished as compared with that of the other side. A person threatened with arteriosclerotic gangrene did not show a reaction to histamine below the knee on either side (fig. 6). A diabetic patient, afflicted with varicose veins, showed a poor response (fig. 7). Another patient with senile gangrene did not show a

	2.5'	5'	10'	15'
Above Knee				
Below Knee				
Leg	NONE	NONE		
Ankle	NONE	NONE	NONE	NONE

Fig. 8.—Results of histamine test in woman with cerebral arteriosclerosis and a slowly healing ulcer on the leg. There were many varicosities of the right leg. A fair pulse was present in the dorsalis pedis and the posterior tibial arteries.

response up to the knee. The patient's leg was amputated just above the knee, and an obliteration of the popliteal artery was found.

A woman with cerebral arteriosclerosis and a slowly healing ulcer on the leg showed a marked delay in the occurrence of the flare below the knee and no reaction at the ankle (fig. 8). Many other abnormal reactions were found (figs. 9, 10 and 11). They will be discussed in detail elsewhere.

COMMENT

In the light of the foregoing data, the chief aim of our treatment for varicose veins must be a decrease of venous pressure. If this can be accomplished, the stagnation of the venous blood, as evidenced by the anoxemia, will be relieved. It is also probable that an increased venous pressure will place considerable burden on the capillaries, the pressure of which follows closely the prevailing venous pressure,⁹ and prevent a normal reaction.

Relief from excess in venous pressure may be accomplished to some extent by elastic support, as shown in table 1. A simple ligation of the saphenous vein will accomplish a decrease temporarily, but the distal part of the vein later fills up through other anastomotic channels. The most efficient way seems to be a surgical removal of the affected segments or an obliteration of the vein by injections. The indications and relative merits of the two procedures have been discussed elsewhere.¹⁹ The relief here is permanent unless other channels open and give rise to the same pressure symptoms. This has been seen to occur following radical excision, whereas the end-results of the injection treatment cannot yet be estimated. Most of the recurrences, however, seem to be due to faulty procedures.¹⁹

The edema seen in varicose veins may be a combination of various factors. Increase in venous pressure alone causes edema, and the

	2.5'	5'	10'	15'
Above Knee	None	None		
Below Knee	None	None		
Leg	None	None		
Ankle	None	None	None	None

Fig. 9.—Results of histamine test in patient with Parkinson's syndrome and a large varicose ulcer, 8 by 10 cm. Much inflammatory reaction and many dilated veins were present. The ulcer healed in five months as a result of the use of casts alone.

edematous area becomes palpable when the volume of the limb increases to 8 per cent.²⁰ But it seems quite probable that the edema seen in venous obstruction is partly lymphatic in origin.²¹

We have already emphasized the effect of anoxemia on cell activity. While the venous congestion and the lymphatic block may be improved by therapeutic measures, the damage to the endothelial lining of the minute vessels is irreversible. Therapeutic efforts to cure chronic edema

19. De Takáts, Géza: Varicose Veins and their Sequelae, J. A. M. A., to be published.

20. Drury, A. N., and Jones, N. W.: Oedema from Congestion, Heart **14**:55, 1928.

21. Reichert, F. L.: The Regeneration of Lymphatics, Arch. Surg. **13**:871 (Dec.) 1926.

following pelvic and femoral thromboses have not been successful up to the present time.

A reliable test for arterial circulation is important. We have interpreted a delay or absence of the histamine flare as an indication of poor arterial flow. If the dilatation of the minute vessels is not followed by an inflow of arterial blood, the increase in surface temperature and the

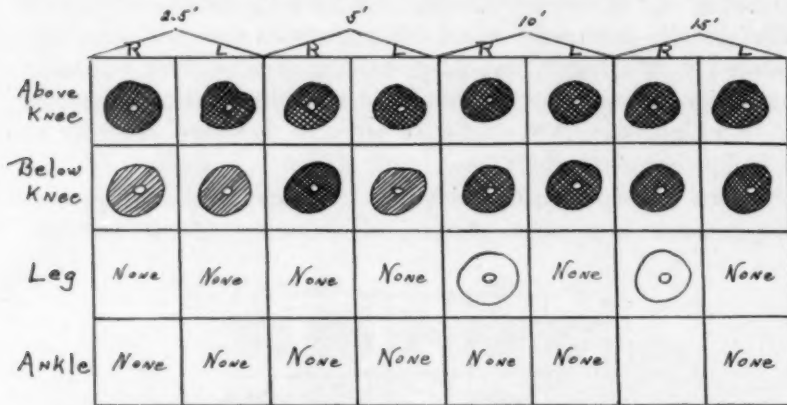


Fig. 10.—Results of histamine test in a physician, aged 56, with a blood pressure of 186 systolic; 100, diastolic. The patient had ringworm of both feet and ankles, more marked on the left foot. He later died during an attack of angina pectoris.

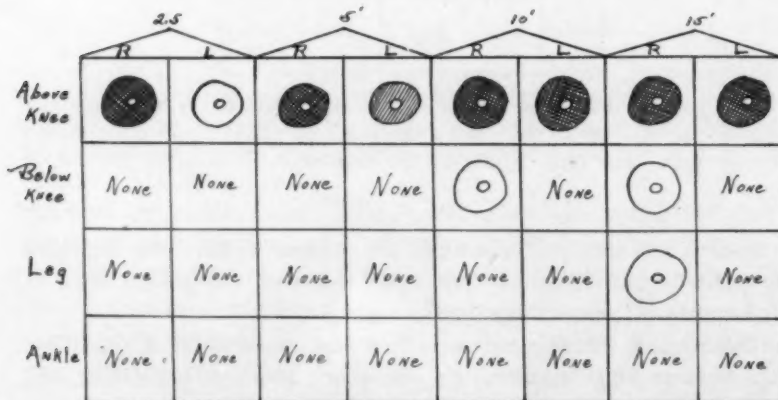


Fig. 11.—Results of histamine test in woman, aged 50, who had had many pregnancies. There was a healed varicose ulcer on the right leg. Appendectomy was performed one month before this test, after which the patient had thrombophlebitis of the left leg.

red flare will not be observed. This condition can be easily reproduced by maintaining on the arm a pressure above systolic blood pressure; the flare will not appear under such conditions below the cuff, but will immediately appear by producing venous congestion with unobstructed

arterial flow.¹⁷ An absence of the histamine flare in cases of varicose veins may also be due perhaps to spasm of the arterioles, which the histamine is unable to overcome. Such a condition can be produced by trying to elicit a histamine flare on top of a wheal produced by an injection of epinephrine. The contraction of the minute vessels produced by a 1:1,000 solution of epinephrine is stronger than that which the histamine solution can overcome. Whether such a clinical condition exists, we are unable to state at the present time. But a normal histamine reaction elsewhere on the skin, with delay on the leg, must exclude a general arteriolar spasticity.

Such a simple test, which can be carried out anywhere, without expensive apparatus and within fifteen minutes, should certainly be applied in every case in which a doubt as to the normal arterial flow exists. Slight decrease of arterial flow in the lower extremity is not uncommon in older patients. Injections should not be undertaken in case of threatening or beginning gangrene. Diabetic gangrene following the injection treatment for varicose veins²² will always be attributed to the injections instead of to the natural course of the disease.

SUMMARY

1. Increase in venous pressure is the predominating symptom of varicose veins. This was measured with a sodium citrate manometer. The influence of posture, of elastic support and of saphenous ligation on venous pressure was studied.

The great increase of hydrostatic pressure in the presence of valvular insufficiency together with a test for the patency of deep veins is emphasized.

2. Besides the postural influence, constricting garters and belts and respiratory movements have a demonstrable effect on venous pressure. Direct determinations with the manometer check fairly closely with the indirect method described by Eyster.

3. The carbon dioxide content of the varicose blood is definitely higher than that of the venous blood in the cubital vein of the same person. The reverse is true of the oxygen content. This local anoxemia and acidosis are marked in some cases and explain the nutritional disturbances in tissues the veins of which are varicose. The varicose eczema and the periosteal thickening are the results of venous congestion. The slow healing of injuries of the skin and the persistence of varicose ulcers may be thus readily explained.

22. McPheeters, H. D., and Rice, Carl: Varicose Veins: Complications Direct and Associated, Following Injection Treatment, *J. A. M. A.* 91:1090 (Oct. 13) 1928.

4. The increase in venous pressure, the poor nutritional state of the endothelial lining of minute vessels due to the anoxemia and a secondary lymphatic block are jointly responsible for the edema seen in the varicose extremity.

5. The adequacy of arterial circulation was tested by the response of skin vessels to histamine. The importance of early recognition of partial arterial occlusion is self-evident.

6. Therapeutic efforts should aim at a decrease or abolition of the increased venous pressure. Radical excision of the affected segments or obliteration by injection treatment will accomplish this result. Edema of long standing, however, is resistant to treatment, possibly because of irreversible damage to the endothelial lining of the minute vessels and lymphatic block.

7. It is pointed out that patients with dilated veins may have an involvement of the arterial flow. The recognition of the latter is of great assistance in the therapy and prognosis of the case.

AN OPERATION FOR THE CURE OF TIC DOULOUREUX

PARTIAL SECTION OF THE SENSORY ROOT AT THE PONS*

WALTER E. DANDY, M.D.

BALTIMORE

Steadily improved by many technical advances, the original intracranial attack on the branches of the trigeminal nerve, independently and almost simultaneously suggested by Hartley¹ of America and Krause² of Germany, has gradually evolved from a procedure of questionable merit and great danger into one of the safest and most successful of major surgical procedures. There are, indeed, few greater triumphs in the history of surgery, for the obstacles at that early period of cranial surgery must have seemed insuperable. But the operation in its most approved form is still far from perfect, largely because of certain disturbances which follow in its wake. With the belief that these defects are now, in a large part, avoidable and with no greater risk to life, another operation for the permanent cure of tic douloureux is proposed.

Although tic douloureux has been recognized as a clinical entity for centuries, its relationship to the trigeminal nerve was long unsuspected because the course and function of the cranial nerves were unknown. In his book, "Die Neuralgie der Trigeminus," Krause³ said that Avicenna (A.D. 1000) gave an accurate description of this disease; that Schlichtung (1748) first cut the infra-orbital nerve for the pain that was called "face neuralgia," and that Nicolous André (1756) first introduced the appellation, tic douloureux. Fothergill (1773) described "a painful affection of the face" with great accuracy, but the disease was then too well known to justify the designation "Fothergill's neuralgia."

Through Galen's period until Meckel's careful dissections of the fifth nerve (1748), the facial nerve was believed to supply not only motor but also sensory function to the face. The fifth nerve was thought to be the nerve of taste (Eckhard). Experimental proof of the sensory function of the fifth nerve and the motor function of the seventh nerve was produced almost simultaneously by Magendie⁴ and Sir Charles

* Submitted for publication, Oct. 1, 1928.

* From the Department of Surgery, The Johns Hopkins University and Hospital.

1. Hartley, F.: Intracranial Neurectomy of the Second and Third Divisions of the Fifth Nerve, *New York M. J.* **55**:317, 1892.

2. Krause, F.: Resection des Trigeminus innerhalb der Schädelhöhle, *Arch. f. klin. Chir.* **44**:821, 1892.

3. Krause, F.: Neuralgie des Trigeminus, Leipzig, F. C. W. Vogel, 1896, p. 103.

4. Magendie, F.: *Textbook of Physiologie*, 1822, English trans. by Revere.

Bell,⁵ about 1821. Despite his accurate anatomic studies and his knowledge that tic douloureux was referable to the domain of the fifth nerve, Sir Charles Bell thought that the origin of tic douloureux was in the sympathetic nervous system: "The painful affection of the face called tic douloureux is seated in the fifth pair and for the most part in the second division of the trigeminal nerve; and so convinced am I that it is the more direct connection established betwixt the sympathetic nerve and the fifth that produces the pain that I would wish to divide the sympathetic in the neck, if I thought it could be done with safety, which it cannot." Though on one occasion he divided the supra-orbital nerve, his great efforts were directed toward the medical treatment of this condition. He frequently referred to successful results with croton oil and colocynth—an accidental discovery—though he later admitted that the results "were not always so happy as in the cases mentioned."

It was the experimental contributions to nerve function which permitted the first rational therapy for tic douloureux. Prior to the experiments of Bell and Magendie, division of a nerve was performed from time to time, but usually the facial nerve was divided. Krause said that in 1778, Langier cut the facial nerve at the stylomastoid foramen, of course without material benefit to the patient, and that Lizars (1821) first cut the inferior dental nerve. It is not impossible that section of the facial nerve might at times have been followed by an appreciable reduction of the pain owing to the absolute rest induced by paralysis of the facial muscles. Neurectomy of the peripheral branches of the trigeminus quickly became the recognized treatment even though the pain always recurred. The general acceptance of this operation is shown by the fact that Wagner, in 1869, had done 135 peripheral neurectomies.

Further progress awaited the advent of anesthesia and aseptic surgery. Perhaps the first suggestion of a more radical treatment was made by Mears⁶ in 1884, who stated:

If in any case I believed . . . that the morbid condition had invaded the Gasserian ganglion I would not hesitate to enlarge anteriorly the oval foramen by the application of a burr to the surgical engine and by traction draw down the ganglion from its position in the fossa upon the anterior surface of the apex of the petrous bone and proceed in a cautious manner to break it up or remove it by sections with the small blunt scissors.

Mears was thinking along the line of attack soon to be proposed and carried out by Rose⁷ (1892), who was in consultation with Ferrier.⁸

5. Bell, Sir Charles: *The Nervous System*, ed. 3. London, 1844.

6. Mears, J. E.: *Study of the Pathological Changes Occurring in Trifacial Neuralgia*, *Am. Surg. A.* **2**:469, 1884.

7. Rose, W.: *Surgical Treatment of Trigeminal Neuralgia*, *Lancet* **1**:295, 1892.

8. Ferrier, D.: *On Paralysis of the Fifth Cranial Nerve*, *Lancet* **1**: 1, 1888.

Bland Sutton⁹ (1886) had previously resected the ramus of the mandible and divided the inferior maxillary nerve at the base of the skull but had not made an effort to enter the cranial chamber. Rose's mutilating operation, in which the ramus of the mandible was removed and the floor of the skull trephined at the foramen ovale, was employed in five cases and the pain relieved. Pieces of the gasserian ganglion were curretted away rather blindly. The amount of ganglion actually removed or destroyed must have been small, for he made the following comment:

It is interesting both from clinical and physiological aspects to observe the rapid diminution of the anaesthetic area, and it would appear that the distribution of sensation is taken up by neighboring branches much in the same way as arterial anastomosis takes place in the vascular system.

It is now clear that the ganglion was not removed but the initial loss of function was due to its injury by trauma. Andrews¹⁰ of Chicago was also working independently on a precisely similar attack about this time. He had published his studies on the cadaver (1891) a year before the appearance of Rose's paper, but he had not performed any operation on the living. Rose's operation received little recognition. It yielded at once to the superior method which appeared during the same year.

Reports of the new intracranial operations of Hartley and Krause were published only a month apart. They were practically identical in conception and execution. Each of these men performed a craniotomy and stripped the dura from the middle fossa of the skull until the second or third branches of the trigeminus appeared. But the efforts of each were then directed toward intracranial section of the peripheral branches of the gasserian ganglion and not to the ganglion itself. As such the procedure was really little superior to the more superficial operations then in vogue. The priority¹¹ of the approach undoubtedly belongs to Hartley, whose publication appeared in March, 1892 (the operation was performed on Aug. 15, 1891), more than a month before the appearance of Krause's paper. The real contribution to the treatment of this condition, however, was the removal of the gasserian ganglion, and the credit for this belongs to Krause¹² (1893). True, it was only a step

9. Sutton, J. B.: Neurotomy of the Third Division of the Fifth Nerve, *M. Chir. Tr.* **71**:107, 1888.

10. Andrews: Paper read before the Section of Surgery and Anatomy, at the American Surgical Association, 1891, p. 153.

11. Because of this almost simultaneous appearance of the papers of Hartley and Krause, Victor Horsley suggested that both be given equal credit. Though the procedure was frequently known as the Hartley-Krause operation, the divided honor was quite naturally not acceptable to either. (Krause: *A Question of Priority in Devising a Method for the Performance of Intracranial Neurectomy in the Fifth Nerve*, *Ann. Surg.* **18**:363, 1893. Hartley: *Intracranial Neurectomy of the Fifth Nerve*, *Ann. Surg.* **17**:571, 1893).

12. Krause, F.: Entfernung des ganglion gasseri und des Central davon gelegenen Trigeminstammes, *Deutsche med. Wchnschr.* **19**:341, 1893.

from intracranial section of the branches of the ganglion to the removal of the ganglion itself, but it was the one big factor in the treatment for tic douloureux. The importance of this step is further emphasized by the prevailing belief (shared by Victor Horsley) that removal of the ganglion was impossible because of its close attachment to the wall of the cavernous sinus.

Antedating the publications of both Krause and Hartley was Victor Horsley's¹³ description (1891) of an unsuccessful operative attack on the sensory root of the trigeminus. The operation was performed four years earlier. Horsley also stated that Macewen independently tried a similar attack on the ganglion, but that as it was unsuccessful a report of it was not published. Horsley's conception of treatment in trigeminal neuralgia by section of the sensory root of the trigeminal nerve with complete disregard of the gasserian ganglion was many years ahead of his time. It was Horsley's belief not only that division of the sensory root would stop the pain just as effectively as removal of the ganglion but that the root would not regenerate; moreover, as already mentioned, as a result of dissections on the cadaver, Horsley thought that the gasserian ganglion was too tightly adherent to the cavernous sinus to permit its separation. Ferrier⁸ shared his views, but there was no evidence at that time to support the assumption. For many years after operations on the gasserian ganglion had been successful, the possibility of merely dividing the sensory root was considered but not carried out because of the absence of proof of its nonregeneration. In a paper with W. W. Keen, who was one of the great pioneers in this field of neurological surgery, Spiller¹⁴ (1898) wrote:

If it could be shown that the sensory root of the Gasserian ganglion does not unite after its fibers are divided, we should have a fact of great importance. Division of this root would probably be a less serious operation than the removal of the entire ganglion and might have the same effect in the relief of pain, but the surgical difficulties might be insurmountable.

Three years later Spiller and Frazier¹⁵ reported the first successful case of intracranial division of the sensory root of the trigeminus, a procedure which has since become more or less a routine. At that time Spiller¹⁶ brought forward, in support of this operation, the literature

13. Horsley, Victor: Remarks on the Various Surgical Procedures Devised for the Relief or Cure of Trigeminal Neuralgia, *Brit. M. J.* **2**:1139, 1191 and 1249 (Nov. 28, Dec. 5 and Dec. 12) 1891.

14. Keen, W. W., and Spiller, W. G.: Remarks on Resection of the Gasserian Ganglion, *Am. J. M. Sc.* **116**:503, 1898.

15. Spiller, W. G., and Frazier, C. H.: The Division of the Sensory Root of the Trigeminal for the Relief of Tic Douloureux, *Univ. Penn. M. Bull.* **14**:341, 1901.

16. Spiller, W. G., and Frazier, C. H.: An Experimental Study of the Regeneration of Posterior Spinal Root: Contributions from the William Pepper Laboratory of Clinical Medicine, *Univ. Penn. M. Bull.*, 1903, p. 4.

on nonregeneration of the pathways in the spinal cord after division and thought that after section of the sensory root of the trigeminus the results would be the same.

Horsley¹⁷ reached the sensory root by an intradural approach, retracting the temporal bone. Although the root was easily found and avulsed, the patient died seven hours later without regaining consciousness. At autopsy neither hemorrhage nor any other cause of death was found. Despite the fact that his patient was emaciated and in poor condition when the operation was attempted, Horsley was quick to see the superiority of Krause's operation. Frazier later succeeded where Horsley failed because he approached the sensory root extradurally and doubtless also because the surgical advances of a decade made the task much easier. It must be remembered that cerebral surgery was just beginning when Horsley attempted to divide the sensory root.

A number of improvements have been added to the original operation on the gasserian ganglion and its posterior root. These have not only made the operation almost devoid of mortality, but have greatly minimized the postoperative sequelae. Horsley (1900) created a small permanent bony defect instead of turning down a bone flap as originally done by Hartley and Krause. This makes the operation shorter and less formidable; it reduces the frequency of extradural hemorrhage, and it allows a more inferior and therefore more direct and easier approach to the ganglion. Tiffany¹⁸ (1896) recommended an intentional incision of the dura in order to evacuate cerebrospinal fluid. This seemingly minor point of technic adds greatly to the ease and safety of the operation. The additional room obtained not only facilitates manipulation in a restricted operative field, but it also reduces the trauma to the temporal lobe (from traction). Moreover, it at once reduces the venous oozing which often impedes the operator's progress.

In his pioneer publication, Rose (1891) suggested preservation of the ophthalmic division of the ganglion as a possible means of preventing postoperative keratitis. Tiffany¹⁹ (1896), too, expressed a hope that deliberate partial section of the gasserian ganglion (the lower two thirds) might be available. Tiffany also suggested the possibility of saving the motor root of the trigeminus and emphasized its importance in the rare cases of bilateral tic douloureux.

A great improvement in the operative treatment of tic douloureux was made by Spiller and Frazier¹⁵ (1901) when they disregarded the

17. Horsley, V.: An Address on the Surgical Treatment of Trigeminal Neuralgia, *Practitioner* **65**:251, 1900.

18. Tiffany: Intracranial Neurectomy and Removal of the Gasserian Ganglion, *Ann. Surg.* **19**:47 (Feb.) 1894.

19. Tiffany: Intracranial Operations for the Cure of Facial Neuralgia, *Ann. Surg.* **24**:575, 1896.

gasserian ganglion and exposed and divided the sensory root behind it. Also, for the first time, they were able to preserve the motor root which lay alongside and mesial to the sensory root. Frazier²⁰ (1925) added still another improvement—perhaps the most important of all—namely, subtotal resection of the posterior root. From morphologic studies, he²¹ concluded that the peripheral branches of the gasserian ganglion were represented in a well defined order in the posterior root. His procedure of choice has since been to segregate and preserve those fibers of the posterior root which correspond to the ophthalmic branch. I shall later comment on this point in considering the function of the trigeminal nerve.

During the past twenty-five years, the operative mortality for all types of operative treatment has been reduced to a low point, i.e., from 0.5 to 1 per cent in the hands of experienced operators who specialize in cranial operations. For reasons which are not clear, the mortality in Germany is still reported around 10 to 12 per cent (Gutnikoff,²² Härtel²³), with operators of the greatest experience. With such a prohibitive operative mortality, it is not surprising that alcoholic injections are in great favor abroad.

It is worthy of note that at the present time all methods of attack on the gasserian ganglion or the sensory root are extradural. Except for Horsley's unsuccessful experience, an intradural attack has not been proposed. The safety of an extradural operation is at once apparent. Not only is the danger of hemorrhage during the operation minimal when the attack is outside the dura but when prolonged retraction is necessary the dura and not the brain receives the brunt of the trauma. It seems probable that the death in Horsley's case was due to traumatic edema.

But with all the technical improvements which have been added, the operation is not without its liabilities. To quote from Frazier²⁰ who, by testing Spiller's beliefs, has introduced nearly all the important additions to Krause's original operation:

But chiefly because of the possibility of corneal complications following the radical operation, the frequency of which has been under- rather than over-estimated, we must admit of the treatment of trigeminal neuralgia, that the last word has not been said.

20. Frazier, C. H.: Subtotal Resection of Sensory Root for Relief of Major Trigeminal Neuralgia, *Arch. Neurol. & Psychiat.* **13**:378 (March) 1925.

21. Frazier, C. H., and Whitehead, E.: The Morphology of the Gasserian Ganglion, *Brain* **48**:458, 1925.

22. Gutnikoff, B.: Treatment of Trigeminal Neuralgia, *Arch. f. klin. Chir.* **135**:79 (April) 1925.

23. Härtel, F.: Surgery of Trifacial Neuralgia, *München. med. Wchnschr.* **71**: 1089, 1924.

First and most important of the postoperative liabilities are the disturbances in the eyes; second, the muscles of mastication are commonly lost on the affected side, which interferes with opening the mouth and with mastication; third, the side of the face becomes sunken due to atrophy of the masseter and temporal muscles; fourth, not infrequently, varying degrees of facial paralysis result, and fifth, epilepsy occasionally follows in the wake of an extradural hemorrhage.

These complications are indeed gradually becoming less frequent owing to the improvements in the operative procedure and to the skill of the experienced surgeons, but they continue to appear even with the best operators. Patients so affected are greatly handicapped, at times even to the point of invalidism. If by other methods it is possible to eliminate these disturbances in part or in whole, the factor of operative safety being equal, the improvement would be most acceptable.

In 1925, I²⁴ presented in a preliminary note an operation by which the sensory root of the trigeminus was divided at the pons, a unilateral cerebellar approach being used. At the time, I entertained little enthusiasm for the procedure as a routine measure in treating persons with tic douloureux because the method then in use was so safe. Moreover, at that time the advantages of the operation, aside from the greater ease of performance, were not appreciated. In certain conditions as, for example, when pain was induced by the invasion of the gasserian ganglion by a malignant tumor, it was indispensable. But at that time there appeared to be no reason to expect any material advantages in the treatment for tic douloureux. However, as the number of cases increased it was observed that the complications of the old method did not appear; there were no corneal disturbances and the motor root was never injured. Moreover, for reasons which will be considered later, after section of the posterior root, sensation of varying amount was usually but not always retained in the face, and without return of the pain. Although there did not seem to be the same need of preserving the fibers of the first branch of the trigeminus since the cornea was not affected after complete section, it was usually just as easy to make a subtotal section of the root as its complete division.

Owing to the great advantages of the subcerebellar route, all patients (88) have been treated by this method during the past two years.

THE OPERATION

A somewhat crescent shaped incision is made in the occipital region on the affected side (fig. 1). The incision begins near the midline and extends in transverse direction just below the origin of the trapezius muscle. Laterally the incision

24. Dandy, W. E.: Section of the Sensory Root of the Trigeminal Nerve at the Pons: Preliminary Report of the Operative Procedure, *Bull. Johns Hopkins Hosp.* **36**: 105 (Feb.) 1925.

turns sharply downward in a straight line to the tip of the mastoid. The trapezius muscle is divided transversely, stripped from the occiput, and retracted downward and somewhat mesially. An area of bone, perhaps 4 by 4 cm., is removed and two extensions of this central defect are made—one toward the cisterna magna, the other toward the mastoid (fig. 1). The latter extension must be carefully made so that the utmost room can be obtained. Cautiously, the bone is nibbled away toward the mastoid cells and the transverse and sigmoid venous sinuses. The mastoid cells are, of course, carefully avoided because of the danger of infection. Occasionally they have been opened accidentally, but with no untoward effect. The

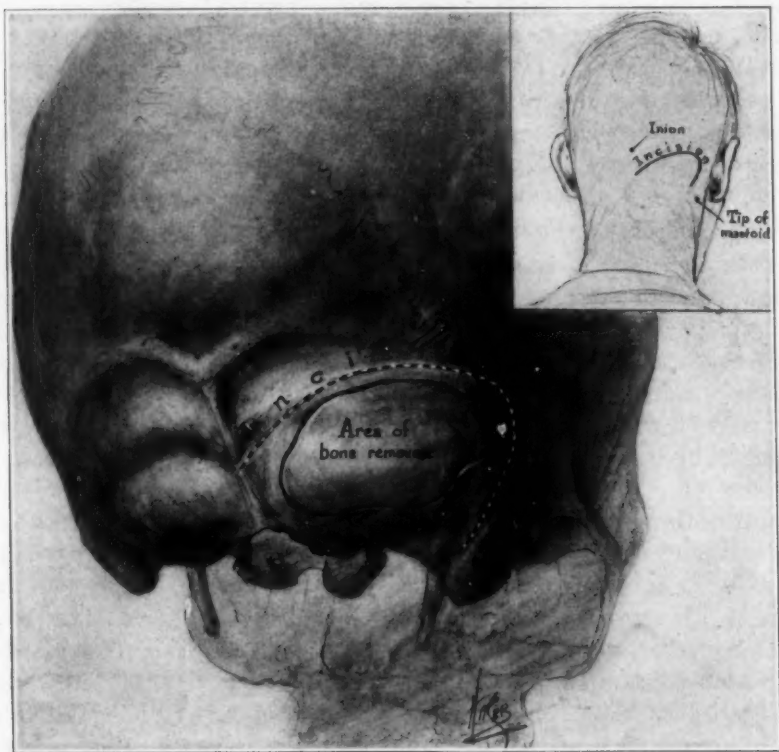


Fig. 1.—Line of incision and bony defect for the approach to the sensory root of the fifth nerve by this operation.

opening, however, is always covered with a flap of dura which is sutured to the periosteum. In the region of the transverse sinus and its junction with the sigmoid sinus, the lateral bony extension can be made larger because the mastoid cells usually stop at a lower level. This extension is really the most important part of the bony defect, for it is from here that the subcerebellar approach is made. The dura is then incised in stellate fashion, and at once the cisterna magna is sought and opened. The release of this fluid provides ample room for exploration (fig. 2).

The cerebellar hemisphere is then elevated with a narrow spatula directed upward and inward (fig. 3 B). The thin membranous covering of the cisterna lateralis, which extends the entire length of the posterior fossa and lines the brain

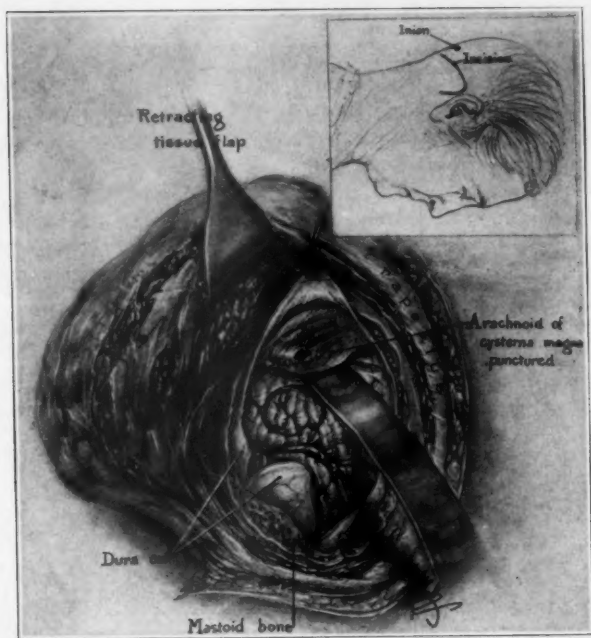


Fig. 2.—Exposure and puncture of the cisterna magna. By the evacuation of this fluid, ample room is obtained to elevate the cerebellum and to expose the sensory root, as shown in the succeeding figure.

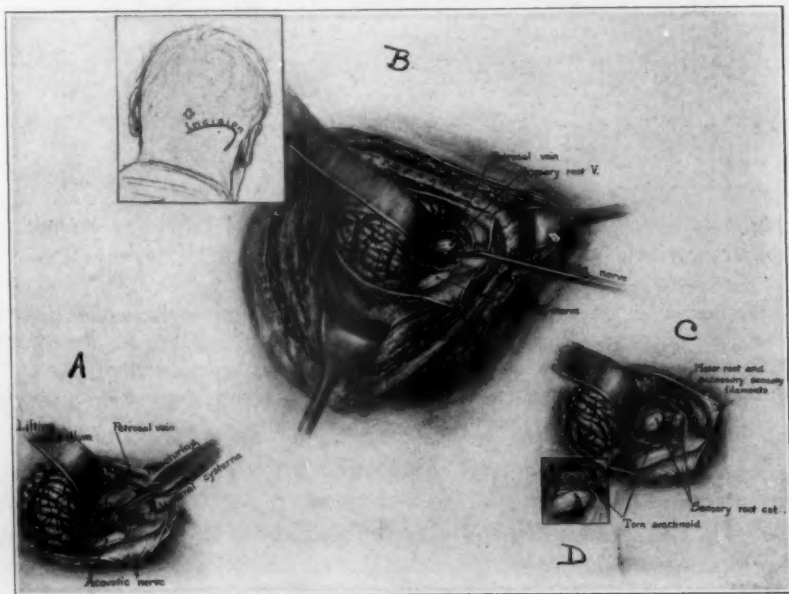


Fig. 3.—*A*, the cisterna lateralis, which is being opened to obtain additional room and to expose the sensory root of the trigeminus; *B*, exposure of the fifth nerve with the blade of the knife inserted beneath the sensory root. Anterior to the sensory root is the petrosal vein, and posterior to it is the eighth nerve; *C*, fifth nerve totally divided with the intact accessory branches anteriorly and beneath; *D*, subtotal section of the sensory root.

stem, is opened between the auditory nerve and the tentorium (fig. 3 *A*). After the collapse of the cisterna lateralis and removal of the loose arachnoid membrane between the auditory nerve and the tentorium, the sensory root of the trigeminus stands out sharply in the depth (fig. 3 *B*). At the incisura tentorii, the petrosal vein crosses from the inferior surface of the cerebellum to the petrosal sinus (fig. 3 *B* and *C*). It lies in and is attached to the outer lining of the cisterna lateralis. The arachnoid membrane must therefore be cautiously removed from the vein to avoid tearing it.

The petrosal vein and the auditory nerve are the two most important landmarks, and between them—they are about 1 to 1.5 cm. apart—the spatula is introduced. The sensory root of the trigeminus is then in full view throughout its course from the tentorium to the pons, a span of from 1 to 1.5 cm. The sensory root lies probably 1 cm. deeper than the petrosal vein. A small blunt dissector at an angle with its long shank is passed between the sensory root and the pons in order to

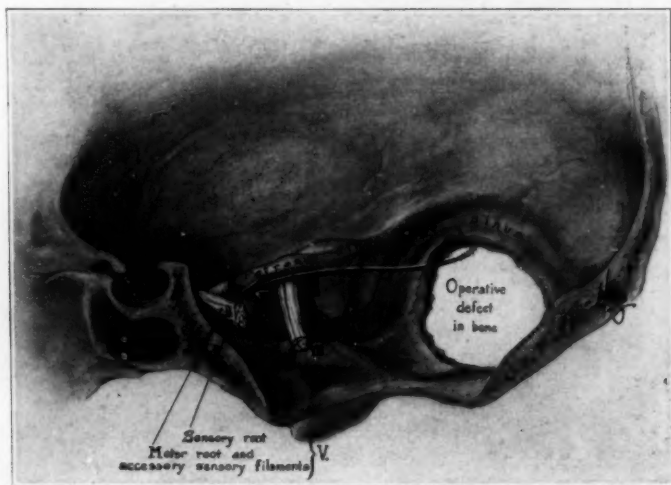


Fig. 4.—Interior of skull, showing route by which the fifth nerve is divided, the cerebellar approach being used.

free the nerve. A small angled knife also on a long flexible shank then follows up the free space between the nerve and the pons and by gentle traction on the blade of the knife, the nerve is severed either in part or whole as desired (fig. 3 *B*). Section of the nerve is usually bloodless; occasionally a tiny bleeding is suppressed by the application of a moist cotton pledget.

The operation is much easier and quicker to perform than the temporal method, for the route is bloodless. Only a few minutes are usually required to elevate the cerebellum, open the cisterna lateralis and aspirate the cerebrospinal fluid and complete the section of the nerve. There are times when the petrosal vein causes trouble because of its inconstant position and size (fig. 8). Occasionally it may obscure the nerve in part or even almost entirely. It is then necessary to retract the vein with the spatula. On two occasions the vein was torn by retraction, but

the bleeding was controlled by packing gently with the moist cotton or by application of a silver clip. Recently when the vein has obscured the sensory root or rendered its exposure difficult, it has been doubly clipped and divided at once. This is made much easier and safer by using flat clips in a long clip holder specially made with the handle bent at right angles to the shaft. The petrosal vein has, in addition, other abnormalities; at times it bifurcates, again it may be double throughout this part of its course, and on two occasions it was absent. In two of the earlier cases the auditory nerve was traumatized by the spatula in trying to avoid or retract the petrosal vein. In neither of these cases did the hear-



Fig. 5.—Scar following operation. Photograph taken one week after the operation.

ing return, although the nerve was intact. In one of these cases the facial nerve also was paralyzed, but the function returned three months later. Only once has the facial nerve actually been seen at the operation. It is usually so well covered by the auditory nerve that it is entirely out of sight. Injury to the auditory nerve must be considered a potential danger of the operation. It should hardly occur again when one can, if necessary, so easily dispose of the petrosal vein. In a recent case, I felt sufficiently secure in this regard to perform the operation despite the fact that the patient was totally deaf in the other ear.

On two occasions, the posterior surface of the cerebellum has been injured but without any subsequent appreciable disturbance of gait or

equilibrium. In one of these cases, a vein running between the tentorium and the cerebellum was torn when the cerebellum was being cautiously elevated. By quickly enlarging the bony defect it was possible to locate and close the bleeding point, evacuate the hematoma and proceed with section of the nerve. In the other case the cerebellum bulged so tightly, despite the release of fluid, that the operation could not proceed until a subsequent stage when the bony opening was enlarged to give more room. Swelling of the brain is a not uncommon sequel of ether anesthesia, but only in this instance has the swelling of the cerebellum been a

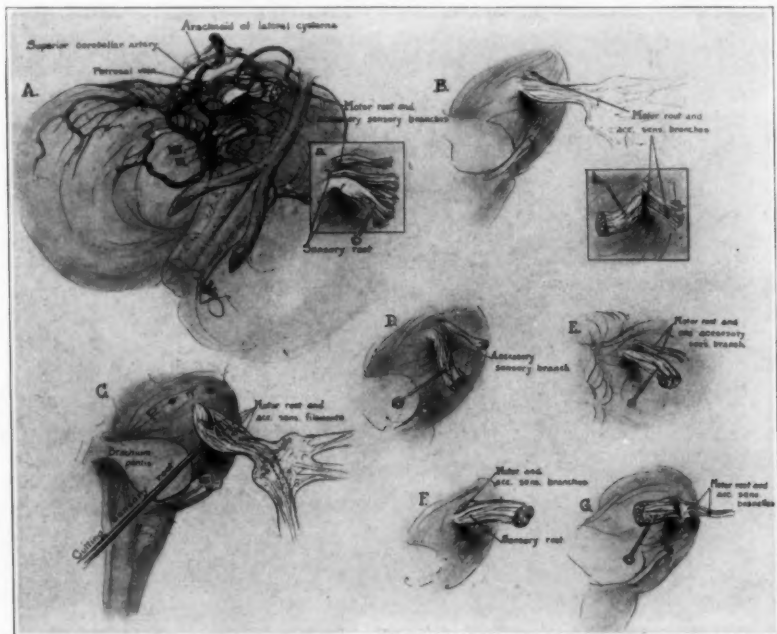


Fig. 6.—A series of sketches of the sensory root, accessory branches and vascular variations in the neighborhood of the pons, where the sensory root is divided. *A* shows an arterial loop which is occasionally present in the neighborhood of the fifth nerve; also the petrosal vein. Occasionally a branch of the petrosal vein descends along the fifth nerve and must be avoided. The arterial loop is a branch of the basilar artery and is suspended freely in the subarachnoid space. Usually it is not in the line of approach to the sensory root. In the insert (*a*) is a sketch of the sensory root and a number of accessory branches. The main sensory root has a fibrous sheath for some distance from the pons; the accessory fibers run loosely and without a sheath. At other times, the main sensory root may have no sheath. *B* and *b* show the position of the accessory filaments of the trigeminus when the main sensory root is retracted forward. *C* shows anastomosis between accessory filaments and the main sensory root; *D*, a single accessory branch which soon joins the main sensory root. Another accessory branch passes with the motor root for some distance before joining the sensory root. *E* shows a single accessory branch running with the motor root for some distance. *F* and *G* show a series of accessory sensory branches which are located ventral to the sensory root instead of anterior to it.

serious handicap. However, in the last thirty operations, rectal ether has been used, with great benefit. The greater available space in the posterior fossa is most striking in all cases and makes the operative procedure easier. There has not been the slightest postoperative disturbance in this series.

Except in the case just mentioned evacuation of the cisterna magna has provided ample room in which to work. Elevation of the cerebellum does not require any force except that necessary to overcome the weight. In fact, care must be taken to obtain room by retraction. It must be obtained by removing bone and fluid. If the bony exposure is not ample, efforts to retract the brain to obtain more room will be injurious to the cerebellum and may cause a crossing vein to tear along the tentorial surface.



Fig 7.—The relations of the arachnoid membrane to the field of operation. The operative approach is through the lateral extension of the subarachnoid space, which is continuous from one cerebellar lobe, across the ventral surface of the pons to the other.

In only one instance has a slight extra-ocular palsy been present, and this—a weakness of the sixth nerve—steadily lessened during the following two weeks. Another patient complained of seeing double, but as the ocular movements were not limited, it was difficult to tell what muscle was involved. Before the patient left the hospital, the vision was greatly improved.

There has been but one death due to the operation; this was due to hemorrhage from a vein along the sensory root. Three patients died of intercurrent diseases before being discharged from the hospital. One patient died of meningitis a week following the operation from a source now known and now preventable. A second patient died of intestinal obstruction which developed ten days after the operation. He had been

sitting up and had recovered from the effects of the operation. A third patient died of cerebral thrombosis two weeks after the operation. She was a questionable operative risk because of hypertension (240). Albumin was found in the urine. Total occlusion of one radial artery indicated the presence of an obliterative process within the arteries. She had twice been refused operative relief at another clinic because of her general condition. Beginning a week after the operation, when she, too, was sitting up, weakness of the left side appeared and gradually increased. Two days before death, signs of intracranial pressure developed, causing the cerebellar wound to bulge. Necropsy showed a diffuse thrombosis involving practically the entire right cerebral hemisphere. The cerebral cortex was swollen and hemorrhagic throughout the entire right hemisphere. The right lateral ventricle was collapsed; the third and left lateral ventricles were dislocated to the left. Since the

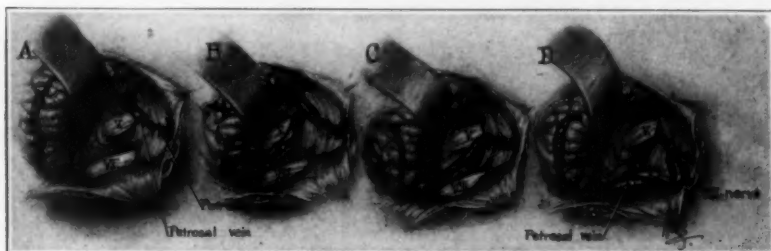


Fig. 8.—Variations in the course of the petrosal vein. The position of this vein is important in making the operation easy or difficult. It is sometimes necessary to divide the vein between silver clips in order safely to expose the sensory root. *A*, usual course; *B*, vein bifurcating between the cerebellum and the tentorium; *C*, vein running posterior to the trigeminus; *D*, vein running along the base of the skull and over the eighth nerve, practically obscuring it.

entire hemisphere was involved, there seems no possible relationship between this process and the remotely removed field of operation.

In the entire series of eighty-eight cases, not a trace of redness of the conjunctiva was found during the first week after the operation. In one case the conjunctiva became reddened ten days after operation, doubtless due to trauma of some form. Subsequently there is, of course, no greater protection of an insensitive cornea following these operations than by the temporal route. Never has the cornea looked dry and lusterless, changes indicative of impending corneal ulceration. Tears have been observed to flow just as freely from the affected as from the other side. Since this method has been adopted, only once has it been necessary to employ the temporal route. In this case a low, congenitally misplaced, transverse venous sinus prevented access to the region of the trigeminal nerve.

A second outstanding result of the series has been that in not a single instance has there been even a transient weakness of the muscles of mastication. The explanation of this fact is that the motor root of the trigeminus is so far removed from the sensory root that there is little occasion to damage it. Usually, the motor root is not seen. The motor root is always mesial and anterior to the sensory division. Obviously, therefore, there has been no instance in which the supra-zygomatic and infra-zygomatic regions have become atrophied and sunken.

The danger of postoperative hemorrhage is always far greater in the temporal region because the branches of the middle meningeal artery and the other arteries supplying the dura are stripped from the bone. Post-operative hemorrhages in that location are indeed not uncommon even after the middle meningeal artery has been ligated, for there is an extensive arterial supply derived from the sphenoidal fissure. The only source of late bleeding in the subcerebellar approach would be from the exposed trapezius muscle, and this should not cause concern if closure is carefully made.

Jacksonian epilepsy occasionally follows in the wake of an extradural hemorrhage owing to the injury to the brain by the clot. This most dreaded of all complications cannot occur if the posterior approach is used, because this approach is far removed from the motor cortex.

Finally, from the standpoint of the surgeon, the operation is much easier. After the bone is removed there is no hemorrhage to combat, and only a few moments are required to expose and divide the nerve. By the temporal route the struggle with bleeding may be long, difficult and exhausting to the operator.

In a short paragraph in a long article on the treatment for tic douloureux by the injection of alcohol, Von Dollinger²⁵ (1912) mentioned the fact that on three occasions he had divided the sensory root beneath the cerebellum. Although this was easier than by the lateral route because of the absence of the tedious bleeding from the cavernous sinus and the middle meningeal artery, he advised giving up all operative treatment in favor of Schloesser's injection of alcohol. A year after my report, Clairmont²⁶ (1926) reported a case in which the operation was by this approach but in which death occurred two days later. He encountered severe bleeding which was eventually controlled, but the patient doubtless died from the effects of trauma.

For the success of the operation one must have a narrow spoon spatula, a tiny knife at right angles to a long flexible shaft, long, thin,

25. Von Dollinger, Julius: Die Behandlung der Trigemineuralgien mit den Schloesserschen Alkoholeinspritzungen, *Deutsche med. Wchnschr.* **38**:297 (Feb. 15) 1912.

26. Clairmont, P.: Zur Behandlung der Gesichtsneuralgia; die Durchtrennung des Nervus trigeminus in der hinteren Schädelgrube, *Deutsche med. Wchnschr.* **15**: 609, 1926.

angled forceps, perfect electrical illumination, a dry field and at the moment of division of the nerve absolutely smooth, even and unobstructed respiration under anesthesia. Trauma to the cerebellum must be avoided. Unless one has the utmost extension of the lateral bony defect and unless the cisterna magna is opened before the cerebellum is elevated, the exposure will be inadequate and any attempt to retract the cerebellum to overcome a defective approach will surely be followed by injury and hemorrhage, which will be not only destruction of function but highly dangerous to life. With an adequate exposure, the operator does not place any pressure on the cerebellum other than the force necessary to counteract its weight. The operation is certainly dangerous unless the operator is perfectly equipped and unless he is well acquainted with the anatomy of this region.

In those patients who were operated on earlier in this series, the sensory root was totally severed. Later, when it became evident how much sensory function was carried by a small accessory filament, a small fragment of the sensory root itself was deliberately left, thereby making it unnecessary to depend on chance accessory fibers. Later, a larger portion (from one-third to one-fourth) of the sensory root was left intact after partial radiculotomy. Partial section of the sensory root was found to be just as easy of performance and much more consistent in superior results. By this method, almost normal sensation is permanently retained over the whole side of the face, even though the pain for which the patient was operated on has been abolished. In effect, the operation appeared to do little more than cut pain fibers and to produce essentially the same result in the domain of the trigeminal nerve as chordotomy for pain in the extremities. In the last twenty cases, partial division of the sensory root has been used exclusively. However, as the original procedure of total division of the sensory root throws much light on the structure and function of the trigeminal nerve, these results have been recorded first and the results of the operation in its present form—partial section—appear later in the paper.

PRESERVATION OF SENSATION IN THE FACE AFTER PRESUMABLY
TOTAL DIVISION OF THE SENSORY ROOT BY THE
CEREBELLAR ROUTE

Since the frequent preservation of sensation in the face and cornea is one of the important features of the cerebellar route, the following sensory examinations following division of the sensory root are presented in some detail.

I. Cases showing total anesthesia.

CASE 1.—In a woman, aged 59, examination on discharge showed complete loss of sensation for touch, pain and temperature over all three branches of the nerve. The corneal reflex was abolished.

CASE 2.—In a woman, aged 63, examined six months after operation, there was total loss of perception of touch, pain and temperature over the entire domain of the fifth nerve. Deep sensation was lost. The corneal reflex was absent.

CASE 3.—In a woman, aged 70, tests made ten days after operation showed complete loss of all forms of sensation. The corneal reflex was absent.

CASE 4.—In a woman, aged 51, examination on discharge ten days after operation showed absolute loss of all forms of sensation over the domain of the severed trigeminal nerve. There was no recognition of deep pressure sensation until tests were made near the periphery of the affected zone. Movement of the skin having normal sensation then made tests for deep sensation impossible. The corneal reflex was absent. Muscles supplied by the motor branch of the trigeminus functioned normally. Vasomotor response was apparently normal. When ice was placed on both lips simultaneously, blanching occurred at the same time on each side, and when the ice was removed the color returned synchronously. When a pin was scratched across both sides of the forehead, upper lip or chin, dermatographia or wheal formation did not develop on either side.

II. *Preservation of touch only (the entire domain of the fifth nerve apparently being similarly affected).*

CASE 5.—In a woman, aged 70, sensory examination on discharge, fifteen days after operation, showed complete loss of perception of sharp and dull stimuli and of heat and cold. Perception of light touch was present everywhere, though it was less acute than on the normal side. All branches were equally affected. Doubleness of objects was recognized accurately.

CASE 6.—Sensory tests, after section of the sensory root of the trigeminus at the pons, showed that the patient could detect and localize light touch (with cotton) at all points over the trigeminal area. She was unable to differentiate between sharp and dull stimuli at any point, nor could she differentiate between heat and cold. There was an active corneal reflex.

III. *Préservation of touch only and over the second and third branches only (total anesthesia of first branch).*

CASE 7.—In a man, aged 56, examined at the time of discharge, eleven days after operation, all forms of sensation were abolished over the area of the first branch; touch was preserved over the second and third branches. Heat and cold and sharp and dull stimuli were not perceived. The corneal reflex was absent.

IV. *Preservation of touch and temperature only (anesthesia for sharp and dull stimuli). All three branches were about equally affected.*

CASE 8.—In a woman, aged 54, in whom sensory tests were made ten days after operation, there was marked hypo-esthesia for all forms of sensation over the affected side. Perception of light touch was everywhere present; heat and cold were detected after delay; sharp and dull stimuli were differentiated though with some uncertainty. A diminished corneal reflex was present.

CASE 9.—In a woman, aged 42, examined one week after operation, all three branches were equally affected. Perception of light touch was everywhere present. Heat and cold were recognized everywhere. Sharp and dull stimuli could not be differentiated. Sharp stimuli registered only as touch. The corneal reflex was abolished.

CASE 10.—In a woman, aged 48, examined on discharge, perception of light touch was everywhere preserved. Heat and cold were accurately recognized, though the acuity was greatly diminished. Sharp and dull stimuli were not recognized

except when the stimulus was extreme. The corneal reflex was present but diminished. Doubleness of objects was registered correctly.

V. Preservation of all forms of sensation over the second and third branches only (the first branch was anesthetic).

CASE 11.—A man, aged 46, had multiple sclerosis. Sensory examination at the time of discharge from the hospital, nine days after operation, showed anesthesia for all forms of sensation over the first branch and part of the second. Some sensation was present over the remainder of the second branch, touch, pain and temperature all being recognized. Over the third branch, all forms of sensation were practically normal. The corneal reflex was absent.

VI. Preservation of touch over all three branches but of heat and cold and of sharp and dull stimuli over the first branch only. (Anesthesia for all sensations, except touch, over the second and third branches).

CASE 12.—Sensory examination showed slightly subnormal sensation for all types over the distribution of the first branch. Over the second and third branches touch was distinguished, but the perception of heat and cold and of sharp and dull stimuli was absent.

VII. Preservation of all forms of sensation in all three branches, but with greatest acuity over the first branch and less over the second and third branches. Usually the sensation over the third branch was still less than the second. In many instances the sensation over the forehead was only slightly if at all subnormal.

CASE 13.—In a man, aged 69, examined at the time of discharge, sensation over the first branch was practically normal. Light touch, pain and temperature were registered accurately everywhere, but with less acuity over the second and third branches. The corneal reflex was normal.

CASE 14.—A man, aged 38, examined on discharge, seven days after operation, did not notice the sensory loss. Light touch with a wisp of cotton was perceived promptly over the entire domain of the fifth nerve; it felt a little keener over the forehead. Heat and cold and sharp and dull stimuli were correctly and promptly recognized everywhere but with greater acuity over the forehead. Sensation over the forehead was a little less than on the normal side. Figure 10 shows that while there are three zones of sensory acuity they do not correspond with the branches of the fifth nerve. The corneal reflex is no less active than that of the normal side.

CASE 15.—Touch was accurately perceived over the entire affected trigeminal domain, though it was less acute than on the other side. Heat and cold were accurately differentiated over all three branches but better over the first branch. Sharp and dull stimuli were also perceived, though with more difficulty than heat and cold. For all forms of sensation the acuity was less than on the normal side. In the supra-orbital region of the side operated on, the acuity was somewhat greater than over the two lower branches. The corneal reflex was present and quite active. Doubleness of objects was accurately recognized.

CASE 16.—Lightest touch was recognized over all three branches. Perception of heat and cold seemed normal over the first branch and was present but greatly diminished over the second and third branches. When two objects were touching the face at any point, their number was correctly noted. Perception of sharp and dull stimuli was normal over the first branch but was poorly differentiated over the second and third branches. There seemed to be patches where sharp stimuli could not be detected. The corneal reflex was as acute as on the normal side.

CASE 17.—In a man, aged 55, examined at the time of discharge, eight days after operation, light touch with cotton, sharp and dull stimuli, deep pressure, heat and cold were appreciated over the entire distribution of the affected trigeminal area, but the acuity of recognition progressively diminished from the forehead to the chin. The left corneal reflex was present but slightly less active than on the other side.

CASE 18.—A man, aged 55, examined one week, and again five months, after operation, had some sensation over the entire affected side. Sensation was greatest over the forehead, less over the cheek and still less over the chin. Light touch was promptly recognized over all three branches, though less than on the normal side. Sharp and dull stimuli were correctly differentiated over all three branches, though with diminishing acuity from above downward. Cold was accurately registered over the entire side of the face. Heat was promptly noticed when applied over the forehead, but not over the cheek and chin. The corneal reflex was nearly as active as on the normal side.

CASE 19.—In a man, aged 60, examined on the eighth day after operation and again ten months later, the results of the tests remained the same on both examinations. Light touch was everywhere recognized, though a little less sharply than on the normal side. Heat and cold and sharp and dull stimuli were recognized over the entire side but somewhat less acutely than the other side. There was slightly greater sensory acuity over the first branch than over the cheek, and still a little more than over the chin. The corneal reflex was active, but slightly less than on the other side.

CASE 20.—In a woman, aged 49, examined on discharge, the ninth day after operation, there was no complete sensory loss. Sensation over the forehead was little if any less than over the side not operated on. Hypo-esthesia for all forms of sensation was present over the second and third branches. The corneal reflex was normal (fig. 11).

VIII. *Preservation of all forms of sensation and of about equal degree over all three branches. Although there was always some hypo-esthesia, it might be so slight as to be detected only with delicate tests.*

CASE 21.—Examination two and one-half months after operation showed the sensation to be but little affected. Light touch, sharp and dull stimuli and slight differences of heat and cold were promptly perceived. The acuity of sensation was definitely a little less than on the normal side. There was no apparent difference in sensation in the three branches. The corneal reflex was practically as active as on the normal side.

CASE 22.—In a man, aged 44, examined on discharge, eight days after operation, all forms of sensation were impaired but present over all three branches. Except for the distribution of the second branch (which had previously been injected with alcohol) the sensory loss was about the same over all branches. The corneal reflex was present but less active than on the normal side.

CASE 23.—In a woman, aged 55, bilateral section of the sensory root was performed at a single operation. She said that feeling on both sides of the face was "natural." Perception of light touch with cotton was intensified everywhere. Heat and cold and sharp and dull stimuli were accurately recognized on both sides. The domain of the fifth nerve could not be mapped out, for the patient said that the sensation was the same as over the area of the cervical nerves. Examination was made at the time of discharge, ten days after operation. The corneal reflex was present on both sides.

The foregoing sensory examinations²⁷ show such greatly variable differences in both the quantity and the quality of the retained sensation that one's credulity might well be tested. At times all forms of sensation are totally abolished. Again all forms of sensation, i. e., light touch, corneal reflex, heat and cold, sharp and dull, may be retained and approximate, though never quite equal to those on the normal side. The difference may indeed be so slight as not to be noticeable to the patient. But regardless of the degree or kind of preserved sensation never has there been a single instance in which a suggestion of the old pain reappeared.

From the cases in which sensation is preserved the only uniform result is the retention of touch, though even this is of varying acuity. At times, touch alone is preserved; at other times touch and temperature only, and in one instance at least cold was accurately recognized when heat was not appreciated (case 18). That heat and cold require separate conduction paths would appear to be indicated by this observation. But it is not fair to place great emphasis on an unsupported single test.

The sensation which remains may be uniformly acute over the whole domain of the fifth nerve; or, again, in other instances it may be more intense in one part than in another. The most frequent observation is greater sensation over the forehead, less over the cheek and still less over the chin. But the variation may obtain in the reverse direction. There appears to be no general plan.

In the foregoing case reports, reference has been made to sensation corresponding with the first, second and third branches. This has been done for convenience only. Such designations, when one is speaking of fractions of the sensory root, may indeed be misleading for it is doubtful if the retained sensation is referable except in a general way to the three peripheral divisions of the nerve. The transition between the shading zones of retained sensation is usually too insensible to make out a sharp line of demarcation. In figure 10, the gradations of sensations conform only in a general way to the three branches of the nerve.

In explanation of these bizarre and seemingly paradoxical sensory sequelae, one might naturally infer that the sensory root had not been completely divided. But the nerve is easy to inspect after its division, and the stumps can be seen. Analysis of the sensation which remains would seem to preclude such an explanation, for why should all branches of the nerve retain sensation if the nerve should have been only partially divided? One would at least expect some part of the face to be rendered totally anesthetic to all forms of sensation. If, on the other hand, the

27. Taste in the anterior two thirds of the tongue has also been carefully tested in a number of these cases. The results have been included in a paper with Dr. Dean Lewis, and will shortly appear in the ARCHIVES OF SURGERY. Taste is not carried by the sensory root or peripheral branches of the trigeminus. It is carried by the facial nerve.

claim is conceded that the sensory root is totally severed, how could the results be explained? And why should division of the sensory root at the pons yield results different from those obtained when it is divided in the dural envelop near the gasserian ganglion? Also why, in so many instances, is the retained sensation greater over the general domain of the first branch than of the other branches of the trigeminus? And why is one form of sensation retained and another lost, and perhaps another only diminished?

In a publication with May (1910), Victor Horsley²⁸ expressed the belief that the motor root carried sensory fibers and adduced both clinical observations and histologic studies to prove his point. In support of their claim, these authors quote Bregmann's²⁹ studies of wallerian degeneration and the discovery of sensory ganglionic cells near the motor nucleus. Van Loudon³⁰ (1907) brought similar evidence to prove that the motor root contained sensory fibers. Van Gehuchten³¹ thought all sensory fibers were in the mesencephalic root.

Sensory fibers in the motor root could not explain the results, for the motor root runs behind the gasserian ganglion and usually blends with the third branch at some distance distal to the ganglion. Therefore, it could not send fibers to the first branch and often not to the second branch. If sensory fibers were carried in the motor root, the third branch would surely contain the most, if not all, sensation, whereas the reverse is usually true, i.e., the ophthalmic branch usually contains most of the sensation which is preserved.

It has been suggested that the gasserian ganglion might function without a central sensory connection, or possibly through the central connection established by the superficial petrosal nerves. Spiller mentioned this possibility when he first suggested division of the posterior root instead of removal of the ganglion. It will be remembered that during the approach to the sensory root by the temporal route, the petrosal nerves are often injured, whereas in the cerebellar approach they are not encountered. It might be assumed that the preservation of this connection might be of value in retaining some function for the ganglion. However, the total anesthesia which results in some cases from section of the posterior root by the cerebellar route must eliminate this theory of independent sensory function of the gasserian ganglion. And because of the total anesthesia, one can also say that the motor

28. May, O., and Horsley, V.: The Mesencephalic Root of the Fifth Nerve, *Brain* **33**:175, 1910.

29. Bregmann in Obersteiner's *Arbeiter* **1**:82, 1892.

30. Van Loudon: Untersuchungen betreffend den zentralen Verlauf des Nervus trigeminus nach intracranialer Durchschneidung seines Stammes, *Petrus Camper. Nederl. bijdr. t. anat.* **4**:285, 1907.

31. Van Gehuchten: De l'origine du pathétique et de la racine supérieure du trijumeau, *Bull. de l'Acad. roy. de Belgique* **29**:417, 1895.

root, at times, at least, does not carry sensory fibers. The evidence, however, is not sufficient to disprove, but it does place a burden of proof on, the theory that sensory fibers are contained within the motor root.

If the sensory observations are correct, as I believe they are, there can be but one explanation, namely, that there must be some anatomic feature of the sensory root which has not been recognized. And if this is true, that feature must be subject to considerable variation.

Examination of the sensory root of the trigeminal nerve reveals a number of accessory branches on which I believe the preservation of sensation depends. Either before or after the dura is reached, they join the main sensory trunk. When the sensory root is divided at the pons, these fibers remain intact and, as is true of the motor root, they may or may not be seen during the operation, being frequently hidden by the tentorium. It is therefore probable that this variable and intact sensory supply explains the differing results which obtain after the operation. The remarkable fact remains that these fibers apparently never carry pain fibers, if this may be assumed from the fact that the old pain of *tic douloureux* has instantly ceased and has not reappeared. Moreover, since there is evidence of dissociation of sensation, there must be specificity of the nerves as carriers. In support of this is the absence of perception of heat and cold with preservation of touch; the retention of temperature sense with the absence of perception of sharp and dull objects; and again the ability to perceive sharp and dull stimuli and at the same time the elimination of the pain of *tic douloureux*.

On the other hand, it is difficult to understand how the small accessory fibers can often assume so much sensory control and over all three branches of the face. From their anterior position one would be prepared to believe that if they should carry sensation it would be only to the domain of the first branch of the nerve. It would seem to explain the greater preservation of sensation in the first branch than in the others, but the fact remains that the other branches retain sensation. One other anatomic observation is noteworthy, i. e., that the accessory branches join each other and also send branches to the fibers of the posterior root before losing their identity.

It is, of course, important to trace the microscopic course of the accessory fibers within the brain stem. Although their position would appear to indicate their destination in the mesencephalic root of the trigeminal rather than in the spinal root, this can as yet only be an inference. The seeming absence of pain fibers in the accessory roots would also appear to be evidence against their participation in the spinal root which is usually presumed to carry the pain fibers.

It is interesting that in two of the four cases of total anesthesia, deep pressure sensation was totally abolished: in the other two cases,

deep sensation was not tested. The pathways of deep sensation have been claimed for both the trigeminal (Davis³²) and the facial (Maloney and Kennedy³³) nerves. These results indicate that deep sensation goes along with other sensations through the trigeminal nerve.

Vasomotor response was tested in two patients in whom all forms of sensation were abolished. It was found to be unchanged. When ice was firmly placed over both sides of the lip simultaneously, the degree of blanching of the mucous membrane was identical on both sides and the red color returned in precisely the same time. A scratch across the forehead or on both cheeks did not cause dermatographia or formation of wheals on either side.

ANATOMIC VARIATIONS OF THE SENSORY ROOT AND THE
ACCESSORY BRANCHES AND OF THE ADJACENT
BLOOD VESSELS

In an occasional case, the motor root is isolated and leaves the pons unaccompanied. But in most specimens there are additional branches of approximately the same size as the motor root and lying alongside. It is, in fact, impossible to tell by gross inspection of the nerve roots which is the motor root and which are sensory branches. That they are sensory is shown by following them in the dural envelop extending toward the gasserian ganglion; the nerves join freely with the sensory root and eventually the motor root runs alone behind the gasserian ganglion to enter the inferior maxillary nerve. The number of these little accessory sensory branches varies up to ten or twelve. The branches on the two sides may or may not be symmetrical. They send filaments to, and receive other filaments from, the main sensory root, forming at times a network of interchanging fibers. The accessory sensory fibers are grouped together at the pons at the point of emergence of the motor root, and an appreciable interval of space—usually 2 or 3 mm.—separates them from the point of entry of the main sensory root. There are, however, variations in this respect, too. In some instances the accessory fibers enter the pons in a continuous line between the motor and sensory root, making all fibers practically continuous. In one instance the line of accessory fibers ran ventral to the sensory root. The accessory branches are never consolidated into a compact root but run individually, having, however, loose, delicate, fibrous attachments to each other.

The main sensory root of the trigeminus also has variations. The size of the root varies greatly; a large root may be three times as large

32. Davis, I. E.: The Deep Sensibility of the Face, *Arch. Neurol. & Psychiat.* 9:283 (March) 1923.

33. Maloney, W. J., and Kennedy, F.: The Sense of Pressure in the Face, Eye, Tongue, *Brain* 34:1, 1911.

as the smallest. The shape of the root at the pons also varies. Usually it is oval or flat from its close relation to the pons; toward the gasserian ganglion it becomes more rounded. The long diameter of the nerve root is usually parallel to the pons, but it may be rotated up to 45 degrees. Its directional plane is important in facilitating the fractional division of the root. When it is lying flattened against the pons, as it usually does, partial section of the nerve is relatively easy, but when it is lying at an angle, the anteriormost part of the root is not visible from the operator's point of view. I have seen this rotation only twice, and in each instance it was the posterior border of the root which was rotated outward. In both instances, section of the entire nerve was necessary.

Variations in the gross structure of the sensory root alongside the pons are also important from an operative standpoint. Usually the nerve is compact and closely bound together by a semblance of a sheath. At times, however, the fibers are quite loosely bound and easily separated, or at least permit the nerve to be split into several parts. This is of importance in permitting partial section of the nerve. Since the blunt instrument which is used to liberate the nerve from the pons may find such an easy line of separation in the nerve, a partial division of the nerve not infrequently results after which the extra fasciculus of the nerve must be separately isolated and divided if total section is desired. In one necropsy specimen the main sensory root was divided into two nearly equal parts by a longitudinal cleft; the one half (posterior) was covered by a sheath; in the other half, the individual roots were loosely held together. Usually evidences of a nerve sheath are absent in the passage through the dural canal.

Vascular variations in this region are important in facilitating or rendering more difficult the operative procedure. Only occasionally does an artery concern the operator, but in two or three instances an arterial loop projects freely in the subarachnoid space and encircles the sensory root. At these times the free loop must be carefully avoided, and the part of the artery between the pons and the sensory root is cautiously isolated from the nerve by blunt dissection before its division with the knife. In one instance it was necessary to depress the free arterial loop, and a small wet cotton pack was used to cover and keep it out of reach during the manipulation of the nerve. This vessel is a branch of the basilar artery (cf. fig. 6 *A*).

It is, however, the variation of the neighboring veins which is of chief concern at operation (fig. 8). The petrosal vein offers the only real problem in the operation. If it is normally placed, there is ample room and it can be disregarded. But there are frequent variations in this vessel. In two operations, the vein was absent. In others, the vein is situated more posteriorly than usual and so partially obscures the nerve. It is then necessary either gradually to elongate and dislocate the vein or

to ligate it with silver clips. At times the vein is formed by the junction of two smaller veins midway between the cerebellum and the petrosal sinus, and the vein may occasionally be double. At times the nerve is sectioned when the surgeon is working anterior to the petrosal vein and occasionally between its branches. In a recent case one half of a bifid petrosal vein ran external to the auditory nerve, which it entirely concealed, and then coursed over the petrous temporal bone from the internal auditory meatus to the petrosal sinus. It was therefore necessary to work in a small opening entirely surrounded by large veins.

Division of the sensory root is usually not attended by bleeding, but on one occasion a vein of some size was divided when the nerve was sectioned and bled quite freely until controlled by a small cotton pack. Examination of several specimens obtained at necropsy revealed in one instance a small branch of the petrosal vein running in the sheath of the nerve. In other cases the nerve seemed free of any vessels of appreciable size. To insure the brain stem against the effects of gentle packing for hemorrhage, which might occur, a small wet cotton pack may be inserted between the pons and sensory root before it is divided.

PARTIAL SECTION OF THE SENSORY ROOT

From embryologic and anatomic studies, Frazier and Whitehead concluded that each branch of the trigeminal nerve was represented by a well defined subdivision of the sensory root, and on that basis Frazier introduced subtotal section of the sensory root in the dural envelop just posterior to the gasserian ganglion, still using the lateral approach. His main object was to spare the nerve supply to the cornea and avoid corneal ulceration. However, the immediate postoperative corneal ulceration is probably not so much dependent on the loss of corneal sensation as on other factors which will be considered later under keratitis. Although there is seemingly less need than formerly to preserve sensation to the eye, it is much better to retain it, other things being equal.

For a technical standpoint, the sensory root can be partially divided at the pons (the cerebellar approach being used) with just as much ease and safety as a total resection of the nerve. Moreover, structural features (the flat oval shape and relative immobility) of the sensory root at the pons make partial section of the sensory root much easier and more expeditious than in the dural envelop where Frazier divides it.

The sensory root is almost round when leaving the gasserian ganglion and in its transit through the dural conduit, but it becomes flattened alongside the pons with the flat surface usually in full view. Fortunately, the sensory root is firmly welded to the pons by a ring of fibrous tissue derived from the inner layer of the pia arachnoid membrane. This layer forms the inner wall of the subarachnoid space. The outer layer is occasionally attached to the fifth nerve at a point near the dura,

but usually continues alongside the dura to the gasserian ganglion, which it partially surrounds, thus permitting much of the ganglion to be covered with cerebrospinal fluid. Division of the sensory root alongside the pons is, therefore, always within the subarachnoid space. It is the fibrous attachment at the pons which permits avulsion of the sensory root (the temporal route being used) with no greater danger of injury to the pons than did its simple division with a knife. Likewise, it is this strong fibrous fixation (together with the paucity of fibrous tissue in the nerve root) which makes it possible partially or totally to divide the sensory root at the pons (by the cerebellar route) without producing injury of the pons.



Figure 9



Figure 10

Fig. 9.—Outline of total anesthesia which followed in only four cases of the series after total division of the sensory root at the pons. The herpes is shown in three branches. This has been considered evidence of traumatic neuritis and as evidence of a trophic function of the nerve.

Fig. 10 (case 14).—Variations in the intensity of sensation after apparently total section of the sensory root. The retained sensation is probably due to accessory branches which are usually associated with the mesencephalic root, though they may also be associated with the spinal root.

In fifteen instances the sensory root has been subtotal sectioned, only the anteriormost fibers being left intact (fig. 3 *D*). The sensory results in the first five cases of partial resection are typical of the others.

CASE 24.—In a man, aged 55, subtotal section of the sensory root was made for pain in the third branch of the nerve. The anteriormost fibers were preserved. A fair estimate of the fibers in the trunk remaining would probably be about one tenth of the whole. Five days later, the sensory examination showed the following:

All forms of sensation were perceived almost as sharply as on the sound side. Sensation seemed equally acute over all three branches. The corneal reflex was no less active than on the other side.

CASE 25.—In a woman, aged 62, the posterior fourteen-fifteenths or more of the sensory root was divided for pain in the third branch of the nerve, only a fine strand remaining. At the time of discharge from the hospital, the only sensory change that was subnormal was a small area in the lower lip and chin (fig. 12), and here the lessened sensation was for sharp and dull objects only; perception of heat and cold and light touch was just as normal as elsewhere. Aside from this hypo-esthesia, there was no greater acuity of sensation of any form over the first division than elsewhere. The acuity of all forms of sensation was the same on both sides of the face. The corneal reflex was present and undiminished. Tears flowed from the affected eye.



Figure 11

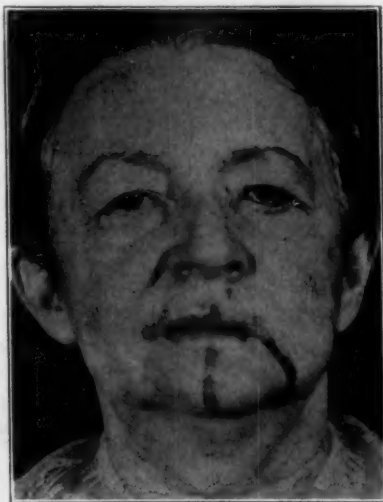


Figure 12

Fig. 11 (case 20).—Normal sensation is retained over most of the forehead. Diminished though preserved sensation is present in the remainder of the trigeminal area, as outlined.

Fig. 12 (case 25).—Except for the small area on the left side of the chin, there is no disturbance of sensation either subjective or objective following subtotal section of the sensory root. The disturbed sensation in this area is restricted to sharp and dull objects only. Other forms of sensation are just as acute as elsewhere.

CASE 26.—In a woman, aged 32, the posterior four fifths of the sensory root was sectioned at the pons for pain in the second and third branches of the nerve. When leaving the hospital one week later, the patient had almost normal sensation over the entire domain of the trigeminus. Subjectively, the patient was unaware of any change in sensation. Objectively, the lightest touch was promptly detected everywhere; there was no appreciable difference in intensity of the sensation according to branches, nor was there any difference between the affected and the normal sides. Sharp and dull objects were instantly and accurately registered. The

slightest difference was not observed according to branches of the trigeminus, nor was the acuity of sensation less than on the normal side. Slight differences of heat and cold were promptly recognized over all three divisions of the nerve, without any appreciable difference over any branch and with no less acuity than on the normal side. When more intense heat was used a slight difference was noted—the only subnormal sensory change—over part of the domain of the second and third branches but not over the first branch. The difference was slight but definite. An attempt was made to map out with some degree of accuracy the exact limits of this lessened sensation, but the transition was not great enough to permit its demarcation. Greater degrees of cold did not produce a different sensory response in the two sides. Sensation of touch, temperature and sharp and dull objects was just as normal over the affected side of the tongue and the mucus membrane of the mouth as on the other side. The corneal reflex was undiminished.

During the patient's stay in the hospital, it was noticed that on three occasions tears flowed only from the eye on the normal side. When this was disclosed to the patient, who was a nurse, she stated that this condition obtained before the operation and followed two unsuccessful attempts to inject the third branch of the nerve one month earlier. After neither injection did the slightest alteration of sensation follow in any part of the face. That this loss of tears was present before operation is shown by the fact that she had told her family physician of the absence of tears after the injections of alcohol. Until this disclosure, it was difficult to believe that partial section of the sensory root could have been the cause, though there seemed no other explanation. It is, in fact, none too clear how the injections of alcohol could have caused this loss of tears. However, there can be no doubt of the unilateral flow and scarcely a doubt of the time of occurrence.

CASE 27.—In a woman, aged 48, subtotal section of the right sensory root was performed for pain in the third branch. About one tenth of the root along the anterior border was left intact. Sensory examination the next morning showed that, subjectively, the patient could detect a slight difference in the two sides, the right being slightly numb over the second and third branches externally, but not in the mouth or on the tongue.

The lightest touch with a wisp of cotton was everywhere promptly perceived. Sharp and dull objects were immediately and accurately differentiated. Heat and cold were at once recognized. The patient detected a slight but definite difference in the intensity of a sharp object and of heat and cold—sensation on the affected (right) side being less acute. There was, however, no appreciable difference over any part of the right trigeminal area; i. e., the same slight hypo-esthesia was present to the same degree over all three branches and within the mouth and over the right side of the tongue. The corneal reflex was present but somewhat diminished.

CASE 28.—In a man, aged 62, with pain in the supra-orbital branch of the trigeminus, the posterior three fourths of the sensory nerve was divided.

After operation, sensation for heat and cold was slightly diminished over all three branches. Light touch everywhere was as acute as on the normal side. The corneal reflex was preserved. Operation was performed one month before this paper was sent for publication.

This is the only instance of the series of partial radiculotomies in which the pain was in the first branch of the nerve. A case of this type puts to the most severe test the claim that there is a separate bundle of pain fibers. If pain fibers to the first branch of the trigeminus were carried in the anterior border of the nerve, as formerly supposed, the operative procedure in this case would have had no effect on the pain.

The sensory examinations after thirty instances of partial division of the nerve show surprisingly little difference from the normal. But the same almost perfect results have also been occasionally obtained when, as I have believed, the entire main sensory root has been divided. If the latter results had not been known the former would surely have been considered impossible, but with the background of the persistent sensory function after presumably total section of the sensory root, the results after partial section do not appear so disturbing and inconsistent. One naturally wonders how it is possible to correlate these results with Frazier's claim that certain parts of the sensory root accurately represent the three peripheral division of the trigeminal nerve. But again the same doubt appeared after total division of the nerve, for the small accessory roots supplied all three branches of the nerve, though often with inequality of sensation in the various branches. It is doubtful whether, because of the network of fibers and accessory branches near the pons, subtotal division of the sensory root at the pons may or may not produce sensory results differing either in quantity or in quality from those following fractional division immediately back of the gasserian ganglion. It is to be regretted that sensory examinations after Frazier's method cannot be offered in comparison. As far as I know, Frazier has not presented postoperative sensory examinations to uphold his views.

If the sensory examinations after either partial or total section of the sensory root are as represented, the conclusions seem inescapable; (1) that after partial division of the sensory root there is no sharp and absolute differentiation of the sensory root into three divisions representing the three peripheral branches, and (2) that a small fraction of the sensory root or even the small accessory sensory branches alone are able to dominate the entire sensory domain of the trigeminal nerve with varying degrees of perfection. It would seem that most, at least, of the peripheral representation of sensation for the trigeminal nerve must lie in the gasserian ganglion.

The results of this study lead to the belief that pain fibers do not leave the main sensory root by any of the branches anastomosing with the accessory fibers. If it were permissible to use logic instead of experiment, it would be reasoned as follows: If Frazier does not find any recurrence of pain after subtotal retrogasserian division of the sensory root, using his anatomic divisions as a guide, the same results should be obtainable by dividing the root at the pons. There is, however, no proof that the position and distribution of the pain fibers may not have shifted in the distance intervening between the point of retrogasserian section and that near the pons. The determination of this point will be possible only by carefully observing a long series of cases of subtotal section.

Since in the cases reported, subtotal section has only been performed recently, the evidence of permanent relief of pain cannot be established. However, the immediate cessation of pain has been just as absolute as after total section of the sensory root. It is necessary to leave such a tiny filament of the nerve to insure sensation approximating the normal that I feel justified in recommending its preservation. However in the more recent operations I have felt safe in leaving from one-quarter to one-third of the sensory root. There has been no return of pain in any case. It should be emphasized that in all of the cases of subtotal section of the sensory root the anteriormost fibers have been retained. Gradually the results have seemed to indicate that the fibers for pain were located in the posterior part of the root.

In estimating the sensation which remains after subtotal division of the sensory root, it must be remembered that the results include the variable accessory fibers in addition to the persisting fraction of the sensory root. The sensation which remains may therefore not always be exactly the same, although apparently it always approaches the normal.

In all but one of the patients in whom subtotal section of the sensory root has been performed, the pain has been located in the third or second and third branches. If one works on the original hypothesis that the anterior fibers of the sensory root supplied all forms of sensation to the first peripheral branch of the nerve, this procedure does not appear unorthodox for pain in the second and third branches. But the post-operative sensory results not only seemed to preclude this hypothesis but suggested that the pain fibers for all three divisions of the trigeminal nerve were in the posterior border of the sensory root (in cross-section). In case 28, therefore, the same subtotal section (of the posterior three fourths of the cross-section of the sensory root) was performed, although the pain was in the supra-orbital branch. This patient's pain stopped immediately (it is now one month since the operation) just as it did in those whose pain was in the second or third branches.

If it is true that pain fibers occupy a separate bundle in the posterior border of the sensory root, the operative treatment has been wholly empiric and successful only by a fortunate chance in the location of these fibers. Had the position of the pain fibers been located along the anterior border of the nerve, all partial sections would have been uniformly unsuccessful.

WHY DOES KERATITIS (CORNEAL ULCERATION) DEVELOP AFTER SECTION OF THE TRIGEMINAL NERVE?

That corneal ulceration (keratitis) promptly followed section of the sensory root of the trigeminus was shown by Magendie over a century ago, when for the first time he divided this root in rabbits and dogs.

When the first operations on the human gasserian ganglion were performed by Rose (1892) precisely the same distressing corneal ulcerations resulted.

At first at a loss to explain the changes, Magendie finally concluded that they must be of trophic origin. He also believed that his experiments justified the claim that the corneal changes developed more rapidly and more intensely when the section was made through the ganglion or in front of it than when the posterior root was divided.

Magendie's illustrious pupil Claude Bernard was also greatly interested in this experiment and accepted Magendie's trophic explanation. To show that contact with the air and the resulting dryness was not responsible for the ulceration, Bernard³⁴ (1858) cut the facial nerve in rabbits and obtained entirely negative results.

Numerous experiments have since brought forth greatly differing conclusions concerning the etiology of this condition. In support of the trophic theory of Magendie were the experiments of von Graefe³⁵ (1854), who excised the lids and lacrimal glands without inducing keratitis. Von Graefe, however, was still cautious in explaining the experiments on a neuropathic basis for which there were so few known facts. Virchow³⁶ (1855), too, though impressed with von Graefe's experiments, still retained an open mind concerning the cause of the corneal disturbance.

Schiff³⁷ (1855) looked on the vascular dilatation of the conjunctiva and sclera as vasomotor changes and thought the keratitis to be of similar origin. Snellen³⁸ (1857) sutured the eyelids together before dividing the trigeminus and prevented keratitis; when the lids were opened ten days later ulceration followed. He naturally concluded that keratitis is of purely traumatic origin. After incomplete section of the trigeminal root, Samuel³⁹ (1860), Büttner (1862) and Meissner⁴⁰ (1867) did not find ulceration of the cornea, even when it was insensitive, and at times ulceration developed when the cornea remained sensitive. From these discordant results, the observers independently concluded that intact fibers were "trophic" and maintained the nutrition of the eye. They even tried to define the exact part of the sensory root

34. Bernard, C.: *Leçons due système nerveux*, Paris, 1858, vol. 1, p. 192.

35. Von Graefe, H.: *Neuroparalytische Hornhautaffection*, *Arch. f. Ophth.* **1**: 306, 1854.

36. Virchow, R.: *Virchows Arch. f. path. Anat.* **8**:33, 1855.

37. Schiff, M.: *Untersuchungen zur Physiologie des Nervensystem*, 1855, vol. 1, p. 91.

38. Snellen, in von Hippel: *Arch. f. Ophth.* **35**:217, 1889.

39. Samuel, S., in von Hippel: *Arch. f. Ophth.* **35**:217, 1889.

40. Meissner, G.: *Ueber die nach der Durchschneidung des Trigeminus am Auge des Kaninchens eintretende Ernährungsstörung*, *Ztschr. f. rationelle Med.*, 1867, no. 29, p. 96.

carrying trophic fibers. Samuel (1860) was able to produce keratitis in dogs merely by stimulating the gasserian ganglion with an electric current. He considered this evidence entirely opposed to any mechanical theory.

From microscopic studies, Senfleben⁴¹ (1875) concluded that the changes in the cornea were "necrotic" and of traumatic origin. Von Hippel⁴² (1889) and Hanau⁴³ (1896) concluded from experiments on closure of the lids that the keratitis is due to drying. Gaule⁴⁴ (1892) found "trophic" pitting of the cornea within a few hours after section of the gasserian ganglion, and in spite of closure of the lids. Hanau kept a dog's eyelids closed for a year after section of the trigeminus. During this time the condition of the eye was perfect, but on the day after the lids were opened ulceration appeared. He said that Gaule's corneal pits could be seen after the cornea was dried from local applications of cocaine. Turner⁴⁵ (1895) found keratitis in only two of eighteen canine experiments in which the sensory root was cut. He did not find evidence to support trophic changes.

Facing nearly every theory are facts which are seemingly but not actually contradictory. It has been noted by several writers that nearly all ulcerations appear within a few days after the operation. If the cornea is clear on discharge from the hospital ten days or two weeks after the operation, the great danger is past. This does not mean that later ulcerations do not develop. Any insensitive cornea, not having a warning sign, is always susceptible to injury from a foreign body, but there is no evidence that an equal stimulus over an equal time would not produce the same degree of ulceration in the normal eye. It is to prevent the later ulcerations from trauma that the retention of corneal sensation by a partial radiculotomy is important. For the prevention of the immediate postoperative ulcerations with which surgeons have been principally concerned, there is probably little, if any, advantage.

The first successful operations on the gasserian ganglion by Rose⁷ (1892) were followed by ulcerations in three of his five cases. In one

41. Senfleben: Ueber die Ursachen und das Wesen der nach Durchschneidung des Trigeminus auftretenden Hirnhautaffection, *Virchows Arch. f. path. Anat.* **65**: 69, 1875.

42. Von Hippel, E.: Zur Aetiologie der Keratitis neuroparalytica, *Arch. f. Ophth.* **35**:217, 1889; Diss. Göttingen, 1889.

43. Hanau, H.: Experimentalkritische Untersuchungen über die Ursache der nach Trigeminusdurchschneidung entstehenden Horn hautveränderungen, *Ztschr. f. Biol.* **16**:146, 1896.

44. Gaule, J.: Die Veränderungen der Hornhaut nach Durchschneidung des Nervus trigeminus, *Cor.-Bl. f. schweiz. Aerzte* **22**:350, 1892.

45. Turner, W. A.: The Results of Section of the Trigeminal Nerve with Reference to the So-Called "Trophic" Influence of the Nerve on the Cornea, *Brit. M. J.* **2**:1279, 1895.

case the eye was lost and in two others the eyes "were very, very bad for a time." . . . "The effect upon the nutrition of the eye is decidedly serious." And in his cases sensation in the ophthalmic branch remained intact. Horsley¹³ thought that corneal ulceration was due to irritation by chloroform and as a preventive closed the lids by suture before the operation. That his reasoning was incorrect is shown by two experimental facts: (1) earlier experiments on animals were conducted without anesthesia, and (2) the normal eye was never affected.

Horsley found four cases of keratitis (one eye was lost) in his first twenty-five cases. Cushing⁴⁶ reported three corneal ulcerations in his first twenty-one cases, and in one case the eye was lost even though sensation of the ophthalmic branch was retained.

One gains the impression that keratitis is becoming less frequent and less severe since the sensory root is divided than when the ganglion was removed. Frazier, Beule,⁴⁷ Bagozzi⁴⁸ and Bastianelli⁴⁹ have reported improved results with this method. However, despite the improvements in subtotal resections of the root, Frazier reported two cases of keratitis in his first twenty-five operations of this type. With Frazier's subtotal radiculotomy, Grant⁵⁰ (1920) gave the percentage of cases of keratitis as about 10.

That corneal ulcerations can be prevented by closure of the lids is indubitable. Moreover, severe ulcerations will heal when the lids are closed. This method, learned from experiments on animals, was early adopted by Krause, Horsley, Keen and others. The fact that keratitis will not develop when the eyelids are closed has been one of the strongest arguments in favor of a pure mechanical theory. Proponents of this theory argue that there must be traumatic insults to the unprotected eye even though they cannot be observed. Opponents of the mechanical theory ask why the onset of keratitis is unusual except immediately after the operation—a fact early demonstrated by Rose and Krause.⁵¹ Keen,⁵²

46. Cushing, H.: The Surgical Aspects of Major Neuralgia of the Trigeminal Nerve, *J. A. M. A.* **44**:773 (March 11) 1905; cont., 860 (March 18) and 1002 (April 1) 1905.

47. Beule: Resection of the Gasserian Ganglion, *Foreign Letter (Belgium)*, *J. A. M. A.* **82**:721 (March 1) 1924.

48. Bagozzi: Un caso di neurotomia retro-gasserina (Ein Fall von Wurzel-durchschneidung des Gasserschen Ganglions), thirty-first congr. di chir., Milano **26**:29, 1924; *Riforma med.* **40**:1111, 1924.

49. Bastianelli: Thirty-first congr. di chir., Milano, 1924, p. 26; *Riforma med.* **40**:1111, 1924.

50. Grant, F. C.: Trigeminal Neuralgia, *M. J. & Rec.* **121**:206, 1925.

51. Krause, F.: Die Physiologie des Trigeminus nach Untersuchungen an Menschen bei denen das ganglion gasseri entfernt worden ist, München, med. Wehnschr. **42**:577, 1895.

52. Keen, W. W., and Mitchell, J. K.: Removal of the Gasserian Ganglion as the Last of Fourteen Operations in Thirteen Years for Tic Douloureux, *Proc. Philadelphia County M. Soc.*, 1894.

Cushing⁵³ and others hoped to obtain the same protection by using Buller's shield, sealed to the face and nose by adhesive tape. They also looked on the retention of moisture as an important feature of the glass shield.

Krause and others had found loss of lacrimation after section of the ophthalmic branch of the eye; Cushing verified his observation. Corneal dryness has since been considered one of the important factors in the causation of keratitis. There is no doubt that the cornea has a telltale, dull, dry and lusterless appearance just before keratitis develops; but, although the eye may be kept moist by the closed chamber with the Buller shield, this has little, if any, value in preventing the onset of keratitis, and there is reason to question whether under its protection ulcers once formed do not develop with greater rapidity owing to the formation of more ideal conditions for bacterial growth. The nerve supply to the lacrimal glands has long been studied without as yet conclusive results. The lacrimal branch of the ophthalmic division of the trigeminus undoubtedly supplies the lacrimal gland, and Krause, Cushing and others have commented on the absence of lacrimal secretion after gasserian operations. The lacrimal gland is also believed to be supplied by the great superficial petrosal branch of the facial nerve. But repeated extirpations of the lacrimal glands have failed to induce corneal ulceration. Even extirpation of the lacrimal glands plus the removal of the eyelids (von Graefe) have failed to produce it.

If the gasserian ganglion or the sensory root is attacked along the temporal fossa, both the great and the small superficial petrosal nerves are almost necessarily sacrificed when the dura is stripped from the base of the skull. Dixon⁵⁴ (1897) early called attention to this fact. It would therefore appear probable that the entire supply of these two nerves would be lost to the lacrimal gland by this operation. By the cerebellar approach the petrosal nerves are not disturbed, and it has been frequently observed that lacrimation is unaffected after this operation in contrast to the observations of Krause and Cushing after the temporal approach. It is not improbable that the loss of the petrosal nerves instead of the division of the fifth nerve explains the difference in the diametrically opposite results. On the other hand, I recently saw a patient from whom a cerebellopontile tumor had been removed one year before. The facial nerve was sacrificed, as is always necessary when the tumor is completely removed. There is no disturbance of function of the fifth

53. Cushing, H.: The Major Trigeminal Neuralgias and Their Surgical Treatment Based on Experiences with 332 Gasserian Operations, *Am. J. M. Sc.* **160**:157, 1920.

54. Dixon, S. F.: On the Course of the Taste Fibers, *Edinburgh M. J.* **1**:395, 1897.

nerve, but she has never had tears from this eye since the operation. This observation needs checking with more cases before the conclusion is drawn that the seventh nerve (through the petrosal branch) alone is responsible for lacrimation; but at least the importance of the nerve is indicated. The more anterior temporal approach of Cushing⁵⁵ and Lexer⁵⁶ may at times spare the petrosal nerves, but this is doubtful for this part of the temporal fossa is difficult to avoid when the ganglion is exposed.

That the absence of lacrimation alone should be responsible for the keratitis does not appear probable: first, because the incidence of keratitis should be much higher, perhaps nearly constant, if the petrosal nerves are always sacrificed, as seems probable, and second, because removal of the lacrimal gland alone does not produce keratitis. It will be recalled that in the experiments of Magendie and Claude Bernard, in which keratitis almost always followed section of the fifth nerve (in rabbits), the approach to the nerve was intradural; injury to the petrosal nerves was therefore precluded.

That keratitis does not develop when the eyelids are sutured together does not mean that extraneous or nonphysiologic trauma to the eye is responsible for the keratitis. It doubtless does mean that the trauma of the movements of the lids causes the ulceration, but this is equivalent to a confession that there is an underlying pathologic condition in the cornea rendering it liable to injury by stimuli which are physiologic and are acceptable to the normal eye.

After every operation on the gasserian ganglion or the sensory root, the eye is carefully protected so that all external trauma can be absolutely excluded. But with this protection, the cases of keratitis continue. It may be argued that this protection reduces the number, but even this is highly questionable. There must, therefore, be some other reason why the cornea is frequently affected in the anesthetic eye and never in the normal eye.

The question of trophic function to any nerve is still being debated without an acceptable conclusion. To anyone who has sectioned the gasserian ganglion or the sensory root, the frequent herpes located in the mucous membrane of the upper and lower lips on the side operated on and always developing from twenty-four to seventy-two hours after operation, must indicate an etiologic relationship to the simple traumatic division of the nerve (fig. 9). Similarly, in herpes zoster the cutaneous changes conforming to the peripheral distribution of the nerve, although the primary lesion is in the ganglion or sensory root of the nerve, must

55. Cushing, H.: A Method of Total Extirpation of the Gasserian Ganglion for Trigeminal Neuralgia, *J. A. M. A.* **34**:1035 (April 28) 1900.

56. Lexer, E.: Zur Operation des Ganglion gasseri nach Erfahrungen an 15 Fallen, *Arch. f. klin. Chir.* **65**:843, 1902.

be evidence of a function of the nerve other than that of simply transmitting sensory or motor stimuli. At a recent meeting of the Missouri-Kansas Neuropsychiatric Society, Dr. A. L. Skoog⁵⁷ demonstrated a remarkable case of lancinating pains associated with cerebrospinal syphilis. Following every attack of pain there appeared, two or three days later, an extensive herpetic eruption in the peripheral distribution of the nerves which were causing the pain.

The end product (herpes) of these inflammatory attacks both in its character and in its distribution seems precisely similar to the postoperative herpes following central operations on the trigeminal nerve. Is not, therefore, the herpes of traumatic origin and an indication of a traumatically disturbed trophic function? During the period when the gasserian ganglion was being removed or the sensory root divided by the temporal route, the occurrence of keratitis seemed to defy all explorations until the conclusion was forced on me that the cases in which the ganglionic dissection was most difficult and prolonged (usually due to hemorrhage) seemed more susceptible to keratitis. This empiric conclusion appeared not to offer any explanation unless trauma to nerves could affect the tissues in the eye in some manner possibly analogous to the production of herpes in the lip, i.e., a traumatic herpes. More and more the conviction has developed that the disturbances of the eyes after trigeminal operations are due to trauma to the ganglion or the sensory root.

WHY SHOULD NOT KERATITIS DEVELOP AFTER SECTION OF THE
SENSORY ROOT AT THE PONS (CEREBELLAR APPROACH)?

That postoperative keratitis can be almost, if not entirely, eliminated by the cerebellar approach here reported is, I think, assured. In explanation, the only important difference (other than the preservation of the petrosal nerve already referred to) appears to be the avoidance of trauma to the ganglion or sensory root. When the temporal approach is used, the ganglion is traumatized before and after the dura is opened; by the cerebellar route, it is only necessary to encircle and divide the nerve. Certain clinical evidence seems to support this explanation. Perhaps the most severe and relatively the greatest number of corneal changes followed the first operations on the gasserian ganglion by Rose. Through an inadequate opening in the floor of the skull, he attempted with only partial success to gouge and scrape away the ganglion. The disastrous corneal changes also occurred despite the fact that sensation to the cornea was always retained. Trauma and not loss of sensation was seemingly responsible for the keratitis.

57. Skoog, A. L.: Case Presented at Missouri-Kansas Neuropsychiatric Society, Kansas City, Oct. 19, 1927, *J. Nerv. & Ment. Dis.* 67:275, 1928.

That keratitis may now be less severe and occur less frequently than formerly would appear to be explained by the technical improvements in operations and the greater skill of the surgeons.

CAN KERATITIS FOLLOW INJURY TO THE SENSORY ROOT?

Whether keratitis can follow injury to the sensory root has been answered in the affirmative in animals, at least, by Magendie's original experiments, but, as already mentioned, he thought that keratitis more readily followed section of the ganglion than of the sensory root. Bernard's experiments also confirmed Magendie's results.

From another line of the operative material, it is possible to transport results which offer an answer for man. When cerebellopontile tumors are completely extirpated—including the capsule—there was such a high percentage of corneal disturbances that now as a routine the eyelids are closed at the end of the operation. In this operation the facial nerve is always destroyed, but the trigeminal nerve is always preserved, though frequently there is an appreciable diminution of sensation. Again it is thought that the trauma is responsible, but in this procedure it is trauma to the sensory root instead of the gasserian ganglion. The facial paralysis undoubtedly predisposes to the development of the corneal change, but as experiments on animals and ample clinical material have shown, facial paralysis alone will not cause keratitis.

It should be noted that herpes of the lips follows the procedure perhaps just as frequently as when the temporal approach is used. Owing to the great frequency of keratitis following the trauma incident to removal of cerebellopontile tumors and to the frequency of herpes after section of the nerve at the pons, it is safe to say that injury to the sensory root produces keratitis just as readily. But in this operation of sectioning the sensory root, far less trauma is inflicted than by the temporal route. If it were necessary to use the same amount of trauma, the results would probably not be any better.

In application of this hypothesis is a recent case in which a cerebellopontile tumor was removed. Dissection of the trigeminal nerve from its attachment to the tumor would have necessitated more than the usual amount of trauma. To avoid this, the nerve was promptly sectioned below the tumor. Despite the coexisting facial paralysis, not the slightest redness of the cornea appeared after the operation.

WHY DOES FACIAL PARALYSIS FOLLOW THE TEMPORAL APPROACH?

Since a temporary facial paralysis resulted in one of the early cases in which the cerebellar route was employed, a complete immunity to this complication cannot be claimed by the new operation. When the tem-

poral approach is used, the frequency of facial paralysis has been reported by Adson⁵⁸ to be about 7 per cent. It is always a discouraging sequel because its avoidance has seemed purely a matter of chance. Three explanations have been offered: (1) the nerve is injured by traction at a point in the face; (2) the nerve is injured at the brain stem when the sensory nerve is avulsed, and (3) the geniculate ganglion is injured by traction on the superficial petrosal nerves when the dura is

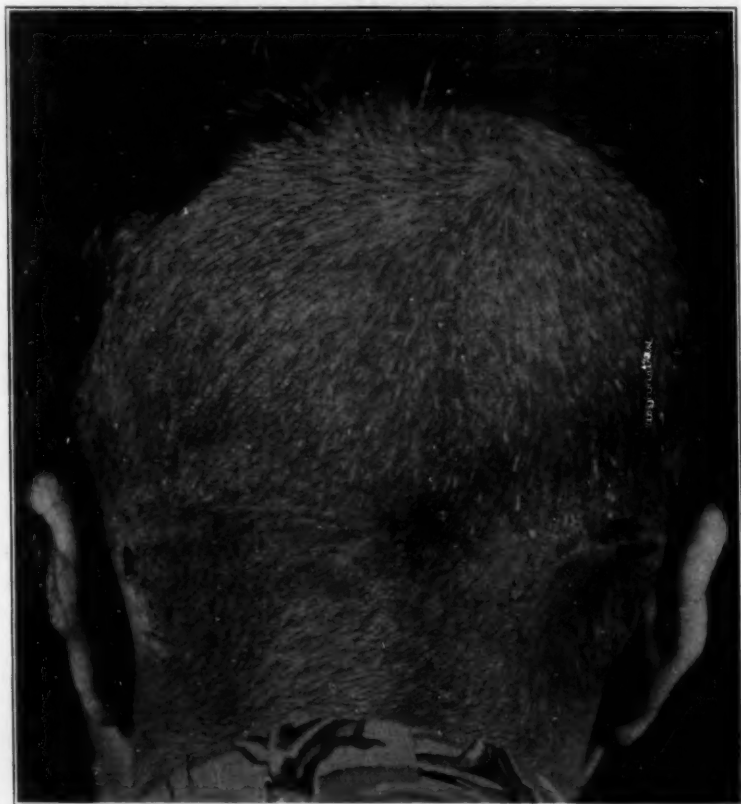


Fig. 13.—Scars following bilateral operation for double tic douloureux.

stripped from the base of the skull. That the facial nerve could be injured in the face is incredible because of the high position of the operative incision. That it is not injured there is easily shown by the test for taste proposed by Dean Lewis in one of my cases. If the injury is peripheral, taste will be unaffected; if it is central, taste will be lost. In one of my patients (operated on by the temporal route), the taste

58. Adson, A. W.: Preservation of the Motor Root of the Gasserian Ganglion During the Division of the Sensory Root for Trifacial Neuralgia, *Surg. Gynec. Obst.* **35**:352, 1922.

was entirely lost. That the facial nerve cannot be injured at the pons by avulsion of the sensory root is evident when the distance between these nerves is appreciated.

Dixon⁵⁴ first called attention to the possibility of injuring the facial nerve at the geniculate ganglion by traction on the petrosal nerve. In opposing the conclusions of Krause⁵¹ that taste was carried from the



Fig. 14.—Appearance of patient after bilateral operation for double tic douloureux.

anterior two thirds of the tongue by the fifth nerve, Dixon reasoned that the facial nerve had probably been traumatized in this way and that the facial injury accounted for the loss of taste. More recently, Alfred S. Taylor⁵⁹ of New York and later Kanaval and Davis⁶⁰ have expressed

59. Taylor, Alfred S.: Personal communication to the author, 1926.

60. Kanaval, A. B., and Davis, L. E.: *Surgical Anatomy of the Trigeminal Nerve*, *Surg. Gynec. Obst.* **34**:357 (March) 1922.

views similar to those of Dixon. Taylor advised division of the petrosal nerves to prevent traction on the geniculate ganglion.

In one of my patients operated on by the temporal route, a relatively large anomalous, obstructing band was cut with a scalpel when the progress of stripping the dura from the roof of the petrous temporal bone had been temporarily halted (fig. 17 B). The nervous character

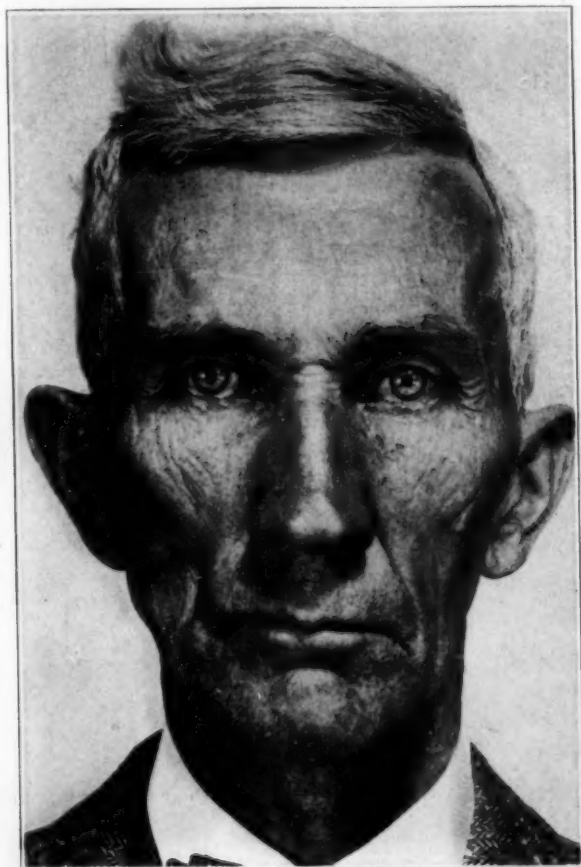


Fig. 15.—Another patient who had the bilateral operation for double tic douloureux. Photograph taken two weeks after operation.

of the structure was recognized as soon as it was cut. In this unusual position the nerve could not be other than the geniculate ganglion, and the prediction was made that the patient would wake up with a facial paralysis. The paralysis was complete at first; a year later, perhaps 75 per cent of the motor function had returned but there remained a tickle facial movement in addition. During this operation it was also found that the roof of the petrous temporal bone was defective at the

point where the geniculate ganglion was cut. Later, a number of skulls were examined, and in two a similar defect was present in the same spot in the root of the petrous temporal bone; in both cases the defect was bilateral. Undoubtedly, therefore, the geniculate ganglion projects through this occasional hiatus in the bone and attaches itself to the overlying dura, from which it can be separated only with varying degrees of injury. Spee⁶¹ (1896) mentioned the fact that such defects occasionally are present in adult skulls and always in children. This he called the "hiatus spurius canalis facialis."

In most instances, the facial paralysis resulting from these injuries is of a mild grade. It is probable that in these cases the geniculate ganglion is injured when the petrosal nerves are torn out of the ganglion

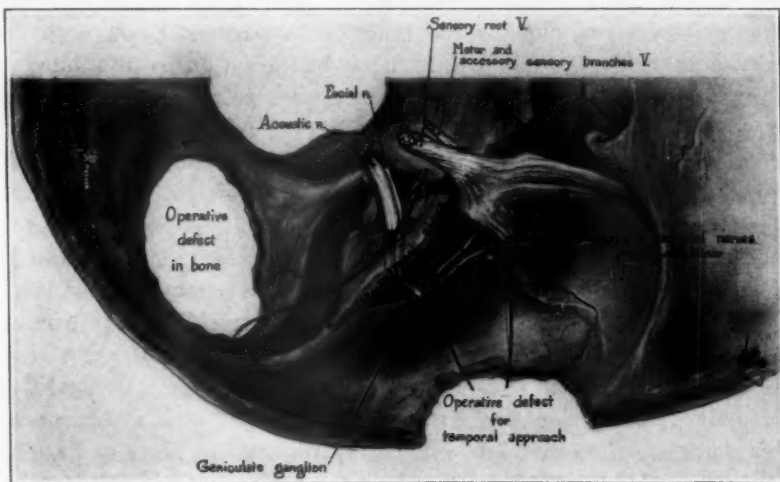


Fig. 16.—When the temporal route is used, facial weakness and paralysis not infrequently follow. Injury to the facial nerve results from trauma to the geniculate ganglion. When the dura, to which the superficial petrosal nerves are frequently attached, is elevated to expose the gasserian ganglion, the petrosal nerves are torn. At times they are pulled out of the geniculate ganglion. Occasionally, the geniculate ganglion protrudes through a congenital defect in the roof of the petrous temporal bone and is attached to the dura (fig. 17 *B*). Direct injury to the geniculate ganglion then causes a more profound facial paralysis.

during the dissection of the dura. The weakness may indeed not be apparent until twenty-four hours or more after the operation, doubtless owing to the slow onset of the effects of edema. Doubtless if the dura in this region were separated from the bone by sharp dissection and the petrosal nerves cut (Taylor's suggestion) (fig. 17 *A*) instead of torn, the facial nerve would escape injury, unless the ganglion itself actually protruded.

61. Spee: *Skeletlehre*; in *Kopf*: *Handbuch der Anatomie des Menschen*, 1896, vol. 1, p. 215.

OPERATION FOR BILATERAL TRIGEMINAL NEURALGIA

Fortunately, bilateral tic douloureux is rare. Krause early called attention to it. Because of a possible later development of tic on the opposite side, Tiffany¹⁹ first suggested that an effort be made to spare the motor branch at the operation. He thought it possible to do so. I have seen but three cases of bilateral tic douloureux. One case came under observation a number of years ago when it was not thought justifiable to suggest any operative relief because the motor branch of the trigeminus had been lost in an earlier ganglionectomy when the pain had been unilateral. The other two patients came for treatment with both sides affected. On each side the characteristic agonizing ticlike paroxysms were being discharged independently, but with greater frequency on the one side than the other. At times there would be a short free interval on one side or the other and occasionally on both, but usually both sides were in pain. Both had been badly mutilated by peripheral operations, but the masseter and temporal muscles still retained function.

Since the motor branch of the trigeminus can be preserved with certainty by the cerebellar approach, it was possible to suggest section of both sensory roots at the same operation. The patients were prepared as for a routine bilateral cerebellar approach. The bony defects toward the mastoid were made on both sides and after the fluid in the cisterna magna was evacuated, each cerebellar hemisphere was lifted in turn and each sensory root divided. The postoperative course of both patients was uneventful (figs. 14 and 15). Anesthesia was total over the domain of both trigeminal areas in one case and partially preserved on both sides in the other. In one case taste was impaired at first but returned to normal during the ten days the patient was in the hospital. In the other case, taste was unaffected. The muscles of mastication were not disturbed; there was no difficulty in swallowing.

Frazier⁶² recently reported a case of bilateral trigeminal neuralgia in which operation was successful, first on one side and several years later on the other. But the patient had a close call from difficulty in swallowing after the operation. The motor branch of one nerve had been sacrificed at the earlier operation, thus placing a heavy burden of responsibility on the preservation of the remaining motor branch. Fortunately the dysphagia was only transient, the motor branch doubtless being merely traumatized.

In a consideration of the treatment for bilateral tic douloureux, the results of Harris⁶³ following injections of the gasserian ganglion with

62. Frazier, C. H.: Division of Sensory Root on Both Sides. First Experience in a Series of 432 Radical Operations for Major Trigeminal Neuralgia, *J. A. M. A.* **87**:1730 (Nov. 20) 1926.

63. Harris, W.: *Neuritis and Neuralgia*, New York, Oxford University Press, 1926, p. 418.

alcohol should be mentioned. He reported two cases of bilateral tic douloureux in which an apparent cure was effected by injections. He found it possible to inject the ganglion with alcohol and still avoid injury to the motor root which lies in apposition. His results appear to have justified his confidence.

NEED OF THIS APPROACH TO RELIEVE PAIN WHEN THE GASSERIAN GANGLION IS INVADED BY CARCINOMA

In one of the cases reported, the gasserian ganglion was invaded by carcinoma which had entered from the nasopharynx. This patient was suffering from the characteristic paroxysmal pain superimposed on a steady burning pain in the two lower branches of the trigeminus. The presence of a tumor seemed probable because of a partial loss of sensation over the domain of the second and third branches. This patient came for treatment when only two or three operations had been done by the cerebellar route and at a time when the favorable points of the operation were not yet in evidence. Exposure of the branches of the gasserian ganglion, the ganglion itself, or the sensory root, though attempted by the temporal route, was impossible because of the extensive growth of the tumor between the dura and the floor of the middle fossa. Since the patient was unable to take morphine, the new cerebellar approach seemed the only solution. As the tumor had not invaded the posterior cranial fossa, division of the posterior root by the cerebellar route did not offer any difficulties.

TRIGEMINAL NEURALGIA CAUSED BY CEREBELLOPONTILE TUMORS

Another important reason for using the cerebellar approach for tic douloureux or trigeminal neuralgia is that occasionally a cerebellopontile tumor may be the underlying cause of the pain. By this approach the tumor can then be discovered and removed. In one patient in the series reported, a typical cerebellopontile (acoustic) tumor was accidentally disclosed in this way.

A man, aged 65, complained of and was observed in typical severe paroxysms of pain along the second and third branches of the fifth nerve. He was totally deaf in the corresponding ear, but the deafness was not considered significant for it had been present for several years and other symptoms had not been present. There was no sensory change, subjective or objective, in the distribution of the trigeminus; the corneal reflex was unchanged. The masseter, temporal and pterygoid muscles functioned equally on the two sides. Other cranial nerves were unaffected. The usual unilateral approach was made. There had been no evidence of pressure; the cisterna magna was large and when evacuated there was ample room to explore the cerebellopontile angle. A typical cerebellopontile tumor—about as large as a pigeon's egg—filled the angle normally occupied by the cistern lateralis. The tumor was much the smallest (6 Gm.) of a large series of cerebellopontile tumors. It shelled out with ease and without the need of a bilateral bony defect which is

usually so urgently needed. The sensory root of the fifth nerve curved around the anterior pole of the tumor. As it was feared that the tic might not cease, the sensory root was then divided. The patient made an uneventful recovery.

While it is uncommon to find tumors of this kind causing trigeminal neuralgia, they do occur occasionally and will be missed by the lateral approach. Tumors of this type are among the most favorable tumors of the brain, and when so discovered by accident at an early stage of their growth their removal becomes easier and the subsequent results should be better.

In addition to this tumor, two aneurysms of the basilar artery were unexpectedly disclosed. There is no evidence that the aneurysms had any etiologic bearing on the neuralgia. The fifth nerve was slightly higher than the aneurysm in each instance.

Weisenburg⁶⁴ (1910) reported a case which in a negative way emphasizes the advantage of the cerebellar route. Unimproved by section of the sensory root by the Hartley-Krause lateral approach, his patient came to necropsy six years later. A cerebellopontile tumor was found. It was the condition found post mortem in this case which led Weisenburg to the discovery of the closely allied tic douloureux of glosso-pharyngeal neuralgia.

OPERATIVE TREATMENT VERSUS INJECTIONS OF ALCOHOL FOR TIC DOULOUREUX

Patients affected with the trigeminal tic douloureux are not infrequently advised to accept injections of alcohol either into the peripheral branches or into the gasserian ganglion as superior treatment instead of operative section of the sensory root. One's view on this subject must be guided by the relative merits and liabilities of each procedure. When operations carry an appreciable mortality, injections of alcohol have every right to paramount consideration. When the operative mortality reaches 12 or 15 per cent, as reported in some clinics, operative treatment should not be considered. But when the mortality is reduced to a fraction of 1 per cent, which obtains with many operators at the present time, any method of surgical treatment demands consideration because it offers a permanent cure. Injections of alcohol never cure. They relieve pain over a period varying from two or three months to two years, the latter period of relief being exceptional. Patients, therefore, must look forward to injections during the remainder of life. As these injections are always painful, by no means uniformly successful and not

64. Weisenburg, T. H.: Cerebello-Pontine Tumor Diagnosed for Six Years as Tic Douloureux: The Symptoms of Irritation of the Ninth and Twelfth Cranial Nerves, *J. A. M. A.* **54**:1600 (May 14) 1910.

infrequently unsuccessful; patients often endure the return of pain for weeks or months before being willing to undergo again the next extremely painful and dreaded ordeal. Succeeding injections tend to become less effective and more difficult, and usually in the late years of life patients finally seek permanent relief by operation.

But much has been said in favor of injections of alcohol, and surgeons have indeed been the first to weigh the liabilities of operative treatment and to suggest injections of alcohol in their stead. Even Frazier, who has reduced the operative liabilities to a minimum, frequently advises injections of alcohol instead of subtotal section of the sensory root. It is the dangers of corneal ulceration and occasional facial paralysis which still confront even subtotal section of the sensory root. I feel strongly that with these difficulties eliminated and with the preser-

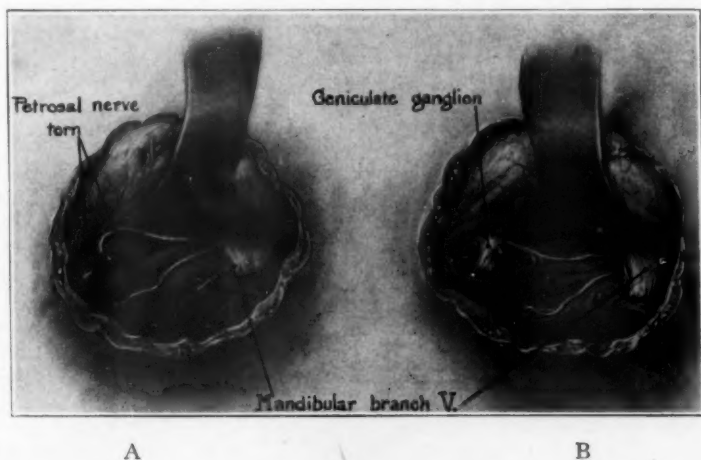


Fig. 17.—Sketch of the superficial petrosal nerves which are attached to the dura and are torn when it is elevated to expose the gasserian ganglion by the temporal route. A sketch of a geniculate ganglion attached directly to the dura is shown in *B*. If the petrosal nerves are cut before the dura is elevated (as suggested by Taylor), many of the injuries to the facial nerve can be avoided. However, when the geniculate ganglion protrudes through a hiatus in the bone and is attached to the dura, it will be difficult, if not impossible, to escape facial paralysis. By the cerebellar route these potential dangers are avoided.

vation of sensation to the face—not infrequently almost normal—that operative permanent relief of pain by the cerebellar route is always indicated, provided, of course, the patient's general condition is satisfactory and if the expectation of life may be several years.

I have not given any consideration to injections of alcohol into the gasserian ganglion because I consider it an indefensible procedure. Easy to perform and theoretically superior in that it offers destruction of the ganglion cells and permanence of relief, it nevertheless leaves a most terrible train of signs and symptoms in its wake. A few years ago the

arguments in its favor sounded so plausible that it seemed an easy solution of this dreadful malady. But in two of four injections the patients went through a terrible ordeal—paralysis of all the homolateral cranial nerves in the posterior cranial fossa and, in addition, dizziness, nystagmus, ataxia, vomiting and staggering gait. Others have had exactly similar experiences. In fact it seems impossible that anyone who uses this method can escape these sequelae. The explanation can be readily understood by injecting 1 cc. of colored solution into the gasserian ganglion of a cadaver. Quickly the color passes around the brain stem and cerebellum (fig. 18). The inner two thirds of the gasserian ganglion is surrounded by cerebrospinal fluid. An extension of the subarachnoid

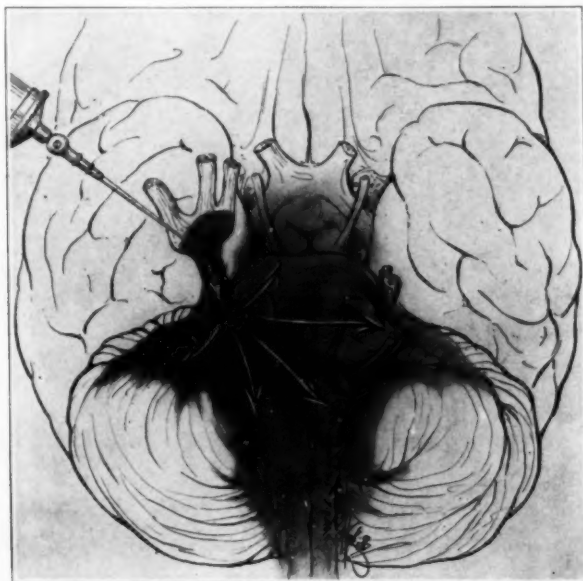


Fig. 18.—Diagram to illustrate the great danger of the injection of alcohol into the gasserian ganglion. The alcohol is injected into the cerebrospinal fluid surrounding the ganglion and immediately passes to the base of the brain, causing a dreadful series of paralyses of all the nerves on the side of the injection, in addition to pronounced disturbance of the cerebellum.

space usually reaches the outer third of the ganglion, and within the subarachnoid space the ganglion is without a sheath. An injection of alcohol into the ganglion therefore readily passes through the nerve into the cerebrospinal fluid, or it may be injected directly into the cerebrospinal fluid. The alcohol then almost instantly attacks the brain stem and the attached cranial nerves.

Many who speak freely of injection of the gasserian ganglion are really performing only a peripheral injection. It is not unusual for

alcohol so injected gradually to spread up the third branch and deaden sensation (though to a lesser degree) in the second branch and even at times in the first branch. In introducing this criticism of injections of the ganglion, I am not unmindful of the superior reports of Harris by this method. His caution in using only a few drops of alcohol seems to indicate his fear of these dreadful experiences.

SUMMARY AND CONCLUSIONS

1. A new operative attack on the sensory root of the trigeminus is presented for the cure of trigeminal tic douloureux. The sensory root is reached at the pons through a bloodless path beneath the cerebellum.

2. The sensory root can be divided either partially or totally. At first, total division of the sensory root was performed. Gradually it was found that by partial section of the root the pain is cured and, at the same time, the sensation to the entire domain of the fifth nerve is little disturbed.

3. Partial section of the sensory root at the pons is now advocated exclusively.

4. The advantages of partial section of the sensory root by the route here proposed are:

(a) Immediate postoperative corneal disturbances are uniformly absent.

(b) The motor root is always preserved.

(c) Sensation, approaching the normal, is retained over the entire domain of the trigeminus, irrespective of the branch involved in the pain.

(d) The corneal reflex is usually preserved.

(e) The approach is bloodless after the dura has been exposed.

(f) The operation is much easier and quicker to perform.

5. The operation is, in effect, essentially that of a cordotomy, in that only pain fibers are sacrificed and all forms of sensation are retained.

6. Observations herein described deny the hypothesis that the peripheral branches of the trigeminus are accurately represented by subdivisions of the sensory root.

7. Some postoperative sensory observations suggest that there are separate nerve fibers for various types of sensation.

8. Pain fibers appear to travel separately and to be located exclusively in the posterior part of the sensory root (in cross-section).

9. Even when the sensory root is totally divided, varying degrees of sensation are retained in the face. At times, this sensation approaches the normal. This is due to the fact that accessory sensory branches usually accompany the motor root and later join the sensory root.

When the accessory branches are absent, anesthesia of the face is complete.

10. The accessory branches of the sensory root apparently never contain pain fibers, nor are pain fibers brought to them by anastomoses with the fibers of the sensory root.

11. The motor root is always preserved because it is at a safe distance from the sensory root.

12. Bilateral tic douloureux can be cured at a single operation by this method because the motor roots are not injured. Two patients have been cured by the bilateral operation.

13. Certain facts seem to indicate that postoperative keratitis is due to trauma of the gasserian ganglion or of the sensory root—traumatic neuritis.

14. Deep sensation to the face is carried through the trigeminal nerve and not the facial.

15. Vasomotor changes do not develop when the fifth nerve is divided.

16. Lacrimation continues after division of the fifth nerve.

17. Facial paralysis results in the temporal approach because the geniculate ganglion is injured, either directly or by tearing the superficial petrosal nerves. These nerves are not injured by the cerebellar approach.

18. Occasionally, tumors in the cerebellopontile angle cause tic douloureux. By this approach, they will be disclosed. The chances of a successful removal are enhanced because the tumor is found earlier. By the temporal route, these tumors would be missed. In the series described, one (unsuspected) tumor was found and successfully removed. Two aneurysms of the basilar artery—presumably not having any bearing on the neuralgia—were found at operation.

19. When malignant tumors invade the gasserian ganglion, relief cannot be obtained by dividing the sensory root by the temporal route. The cerebellar route is indispensable in such cases.

EXOPHTHALMIC GOITER

INDICATIONS FOR THE STAGE-OPERATION *

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There are divergent opinions as to the need for the stage-operation in present day surgical procedures on the thyroid gland. The range of these views is wide; on the one hand are surgeons who advocate and practice multiple preliminary ligation and lobectomy for exophthalmic goiter in a large proportion of their cases in a manner similar to that generally practiced before the advent of iodine in the preparation of the patient for operation; on the other hand are those who scoff at this as a timid surgical measure and advocate its complete abandonment. Between these extremists are surgeons who recognize advantages in the stage-operation and advocate its use in a restricted group of cases. In view of the fact that only a few years ago the stage-operation was almost universally employed in surgical treatment for exophthalmic goiter, and that today there exists a wide difference of opinion concerning its need, it seems timely to review the circumstances under which it was developed, including the purposes for which it was designed, and the indications for its employment, and to determine, if possible, whether recent advances in surgical treatment for goiter have altered these purposes and indications.

In the course of the development of surgical procedures on the thyroid gland, it is apparent that the stage-procedure was evolved to meet a twofold purpose. At first, it was designed solely to overcome technical difficulties. In the period before Lister, hemorrhage and sepsis were almost inevitable complications of the operation for the removal of a tumor of the thyroid gland, and a successful outcome was the exception rather than the rule. Ligation of one or more of the principal arteries to the gland was proposed as an alternative procedure with the hope of reducing its vascularity and producing shrinkage of the tumor by atrophy (Porta and Blizzard). As surgical technic improved under the impetus given to it by the introduction of asepsis and it was learned that tumors of the thyroid gland could be removed with a reasonable chance of success, the operation was at first limited mainly to excision of the larger lobe, the second lobe to be resected later only in event of its

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subsequent enlargement. Indeed, this practice continued until within recent years, when it was appreciated that the ideal operation for goiter consisted in the resection of both lobes if both were involved.

Later, after resection of the thyroid gland had become an established procedure, a second reason for dividing the procedure into stages was discovered, namely, to combat the intense hyperthyroidism of exophthalmic goiter or its resulting debility. This discovery was destined to play an important rôle in finally establishing surgical intervention as the pre-eminent therapeutic agency in the treatment for exophthalmic goiter.

Although exophthalmic goiter was recognized as an entity in the first quarter of the nineteenth century, it was not until its last quarter that the value of surgical measures in its treatment was first demonstrated (Tillaux, Rehn and Mikulicz). Progress in this field was exceedingly slow. Although Kocher had standardized the technic of the operation for partial thyroidectomy and had reported a series of 250 operations for nodular goiter with the exceedingly low mortality rate of 2.4 per cent, attempts at removal of exophthalmic goiter were followed by a high mortality. It was evident that the problem in the surgical treatment of exophthalmic goiter was different. Although the technical difficulties were often greater than those in the removal of the nodular goiter, the failures could not always be attributed to faulty technic, for often within a few hours after the goiter had been removed successfully, severe postoperative crises would supervene, with extreme tachycardia, high fever, nausea, vomiting, restlessness, cyanosis, great prostration, mental stimulation and delirium, and frequently coma and death within from twelve to twenty-four hours. The cause and nature of these were unknown. The surgeon was baffled, but wider experience made clear that the problem of reducing the operative mortality lay not so much in the improvement of technic as in the further study of the disease itself, and the control of the hyperthyroid reactions. As the progress of the reaction could not be effectually checked, hope lay in prevention, and efforts were directed at means of reducing the intensity of the hyperthyroidism and affording protection to the patient. Then under the leadership of a few surgeons, notably, C. H. Mayo, Halsted, Crile and Kocher, it was accidentally learned that during certain phases, when the degree of hyperthyroidism was greatest, or when the debility of the patient was extreme, the substitution of ligation of the vessels in stages, at a diminished hazard, might so improve the patient's condition that the thyroid gland could be resected later without the risk of acute reaction. For the same purpose, the operation might be divided into many stages.

A review of the literature does not make clear who was the first to ligate for the purpose of improving the condition of the patient with exophthalmic goiter in preparation for subsequent resection of the

gland. History reveals, however, that the operation was first performed in 1811 by an Italian, Luigi Porta, later by Sir William Blizard, Billroth, Wölfler, Kocher and others, but the procedure was undertaken solely as a substitute for resection of the gland in order to avoid the technical difficulties of the latter with its frequent complications of hemorrhage, sepsis and choking.

In the Mayo Clinic, the operation was first performed by C. H. Mayo in 1908, and to him belongs the credit for demonstrating, by means of a large group of cases, the immense value of the stage-operation in reducing the mortality rate in cases of exophthalmic goiter. At first in these cases the operation of ligation was not previously planned but was decided on in the operating room after the flap had been raised in preparation for partial thyroidectomy, when the condition of the patient became so critical that it seemed unwise to proceed with the resection; one or both of the superior thyroid vessels were ligated as a makeshift in the hope that some benefit might result. The improvement in the patient's condition following this was so marked that its value was immediately appreciated. The procedure was proposed as a preparatory step to partial thyroidectomy in the severe cases and as a possible substitute for thyroidectomy in the milder cases. Polar ligation soon became used more extensively and was then done as a premeditated step in a graduated procedure, through a small separate transverse incision made over the pole of the gland. As experience increased, polar ligation was employed not solely as a preparatory measure, but as a test of tolerance; that is, simple preliminary ligation was done as a test in the milder form of the disease when preparatory surgical measures were not clearly indicated, yet partial thyroidectomy could not be performed with complete assurance that a severe explosive reaction would not supervene. If a reaction was not thus provoked, it was interpreted as a fairly accurate criterion that the patient would safely endure partial thyroidectomy. If, however, the ligation was followed by a reaction of tachycardia, fever, nausea, vomiting, extreme restlessness and prostration, this was recognized as definite evidence that further rest and preparatory surgical measures were indicated. Modifications were added; Halsted practiced ligation of the inferior instead of the superior thyroid artery. Later, when resection of both lobes became standardized for partial thyroidectomy in exophthalmic goiter, the principle of operating in stages was again applied, and only one lobe was resected at one stage. And so it was not unusual for a patient with a severe form of exophthalmic goiter to be submitted to four, five or even six distinct operative procedures at intervals of from three days to three months, before he was finally rid of his goiter. Contrasted with the primary complete operation in one stage, the additional burden consequent on the multiple-stage operation appears a staggering price to pay. Besides the

pain and suffering and the additional scarring, the time consumed has been from eight to ten months longer with a similar prolongation of the period of disability. The economic loss reckoned solely on the hospital expense has been from four to six times greater. When it is taken into consideration, however, that the stage-operation practically decimated the operative mortality, this price seems rather insignificant.

In America particularly, the stage-operation was accepted almost universally as a rational measure, and its practice continued to widen with increasingly gratifying results. The specter of a high mortality rate no longer deterred the patient with exophthalmic goiter from submitting to operation until forced to do so as a measure of last resort, and as the number of earlier operations increased, the operative and end-results improved.

Indications for preliminary ligation and lobectomy were not standardized, but varied with the personal judgment of the individual surgeon in assessing the many factors which he believed influenced the operative mortality. It was generally conceded that it was not safe to perform primary subtotal thyroidectomy during certain phases of the disease, as in a crisis or immediately following it, or in the presence of severe hyperthyroidism with a high basal metabolic rate, marked cerebral stimulation, nausea, vomiting and diarrhea, or in the presence of marked debility as evidenced by great loss of weight and strength, or in the presence of intercurrent low-grade infection. The absence of these, however, could not be accepted as a reliable criterion that the patient would tolerate primary thyroidectomy. It was recognized that there were many gradations in the intensity of the disease, sometimes without any clearcut tangible evidence to separate the good risk from the bad, since occasionally severe reaction occurred when the patient was judged clinically to be a good risk. Without warning signals, how was this danger to be avoided? It is natural that in the mind of the surgeon there existed an element of uncertainty as to the operative risk in nearly every case of moderate severity, and in order to fortify his own conscience he employed preliminary procedures more extensively than was actually necessary. In this group he had to be guided by his own experience, and thus different surgeons formulated their own indications for ligation and lobectomy, each stressing a different feature, such as the degree of weight lost, muscular weakness, general debility, basal metabolic rate and the reaction of the patient on the operating table as noted by change in pulse rate, blood pressure, excitability and the like. Many of these efforts for safety were more sincere than intelligent.

The extent of the development of the multiple-stage procedure may be judged by the number of stage-operations performed in the Mayo Clinic during 1921. On only 30 per cent of the patients with exophthalmic goiter was primary subtotal thyroidectomy performed. On the

remaining 70 per cent, from two to five procedures were carried out. Such was the status of the stage-operation when, in March, 1922, the administration of iodine to patients under preparation for operation was introduced by Plummer. On account of the then universally accepted teachings that its use was definitely contraindicated in exophthalmic goiter, iodine was at first cautiously given in small doses for a short period to a few carefully selected patients. The clinical improvement of these patients was immediately appreciated, but not until after an experience of several months did this change of preparatory treatment have any noticeable influence in the selection of the type of operation. In this formative period, before the preparatory treatment was standardized, severe postoperative hyperthyroid reaction and pulmonary complications were noted occasionally in patients inadequately prepared, as had been previously noted in patients who had not been treated with iodine. Gradually, as experience increased, it was realized that just as the administration of iodine to patients with exophthalmic goiter could prevent and control practically all the spontaneous crises of the disease, so could it prevent and control most of those induced by operation. Accordingly, the dosage of iodine was increased and the period of preparation prolonged; this resulted in striking improvement in the patient's condition and noticeable reduction in the intensity of the postoperative reaction. Even then there was hesitation in the acceptance for primary complete operation of the greatly improved patient who on admission two weeks previously had manifested all the symptoms of that phase of the disease which it had been previously learned by experience made operation unsafe. The principles of surgical management developed through years of alternate hope and disappointment are not so easily cast aside. While it was apparent that there was not the same need for the multiple operations, the surgeon did not have experience or teachings to draw from, and so had to blaze a new trail. In adjusting himself to meet this change wrought by iodine, the surgeon could not jeopardize the safety of the patient and so had to proceed cautiously before making any radical changes in the stage-operation.

In the Mayo Clinic for the last six years the preparation of the patient with exophthalmic goiter has been standardized, and during this time more than 5,000 patients have been operated on with a steadily decreasing mortality. The method of preparation has been published in detail on different occasions, and I shall not discuss it here. I wish only to cite a few principles which seem worthy of emphasis. In estimating whether a patient is ready for operation, it is important to consider the two additional operative hazards, postoperative crisis if the patient's condition is acutely toxic and postoperative pulmonary infection if the patient is greatly debilitated. For the patients who are judged bad risks, the preparatory measures should be continued as long as there

is definite improvement, as noted either in the reduction of the intensity of the hyperthyroidism or in the gain in general strength. An important point in the preparation, often not appreciated, is the debilitating effect of prolonged rest in bed. A patient is a far better surgical risk if he is allowed to be up and about in the hospital for at least a week before operation.

I am convinced that fully 98 per cent of all patients with exophthalmic goiter can be made safe surgical risks by proper medical management, and that the stage-operation as a supplemental preparatory measure is indicated in a very small group of patients. The patients who apparently respond least to the administration of iodine are in a group of late cases of moderate or relatively high hyperthyroidism in which there is a hard "trained" goiter. When the goiter is large and the degree of hyperthyroidism is high, a stage-operation may be defin-

Operations on the Thyroid Gland from Jan. 1, 1927, to Jan. 1, 1928

	Cases	Mor- tality	Per Cent
Exophthalmic goiter			
Primary subtotal thyroidectomy.....	1,500	0	
Two-stage thyroidectomy	8	2	
Polar ligation	9		
Total.....	1,500	11	0.72
Subtotal thyroidectomy for adenomatous goiter without hyperthyroidism	502	1	0.19
Subtotal thyroidectomy for adenomatous goiter with hyperthyroidism....	615	5	0.81
Carcinoma	37		
Total.....	2,674	17	0.63

itely indicated as an additional safeguard. In the Mayo Clinic during 1927, operation was performed on 1,520 patients with exophthalmic goiter. Polar ligation was performed in only nine cases, and in only eight were there indications for dividing the resection into two stages. Eleven patients died, a mortality of 0.72 per cent. Two died following the first stage lobectomy.

It is not possible to establish iron-clad rules to govern the selection of the type of case in which the stage-operation is indicated. Every case must be judged solely as an individual case and the experience of the surgeon must dictate according to his interpretation of the operative hazard.

INDICATIONS FOR STAGE-OPERATION

Ligation.—The benefits of polar ligation as a preparatory measure are obtained by reducing the intensity of the hyperthyroidism. The group of patients who receive the greatest benefit from ligation are the same as the group in which treatment with iodine is most effective. The early case of severe hyperthyroidism, with pronounced bruit and thrill over the thyroid vessels, responds in a striking manner to ligation, but in this group iodine is even more effective. In the late cases with the hard,

trained gland, iodine often apparently does not affect the course of the disease. In cases of this group in which benefit has not been derived by treatment with iodine, and in which the operative risk is considered poor on account of the intensity of the hyperthyroidism, ligation should be performed as a preliminary procedure. It has been my experience, however, that if treatment with iodine fails to influence the course of the disease, ligation is equally ineffective. Indeed, in some instances the substitution of ligation for partial thyroidectomy may prove unwise, for it must be remembered that during the course of the disease there

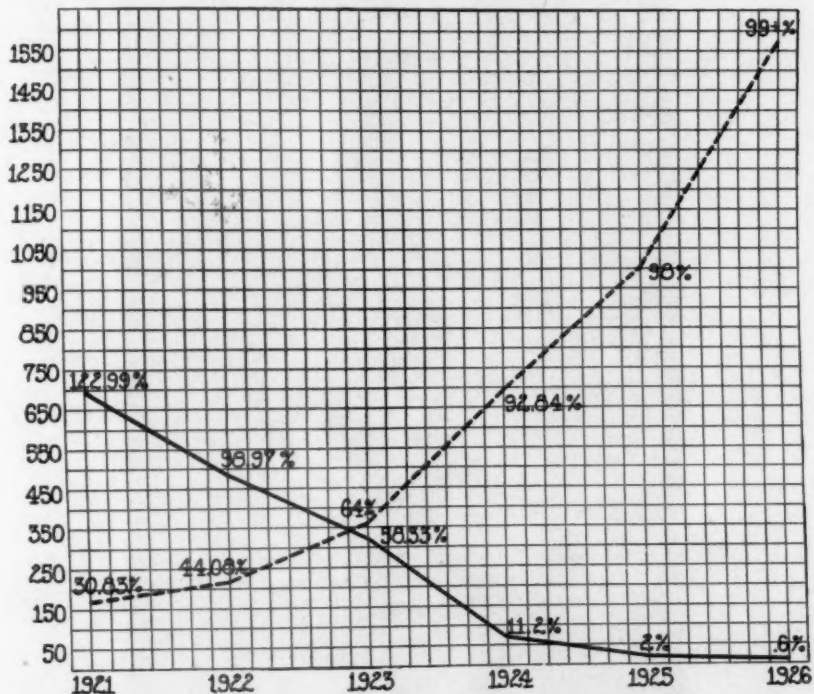


Fig. 1.—Increase in percentage and number of primary thyroidectomies (broken line) and decrease in percentage and number of ligations (solid line). The use of iodine was begun in March, 1922.

may be a certain favorable time for performing partial thyroidectomy, and if this time is allowed to pass, operation may prove more hazardous. Since the standardization of the present regimen for preparing patients, the employment of ligation has not exceeded 2 per cent of the number of operations (fig. 1).

Lobectomy.—There is still a limited number of patients with exophthalmic goiter who cannot be made safe surgical risks by prolonged medical treatment. Most of these have had the goiter for two years or longer; the gland is usually firm, and technically it may be

difficult to resect. The basal metabolic rates are high or moderately high and are only slightly affected by the administration of iodine. Such patients (figs. 2 and 3) are likely also to be handicapped by the presence of visceral degeneration (heart, liver, kidney, muscles, etc.). Most of these will safely tolerate uncomplicated subtotal thyroidectomy, but would be likely to succumb if there were any additional burden such as is imposed by a technical error. Obviously, the greater part of the

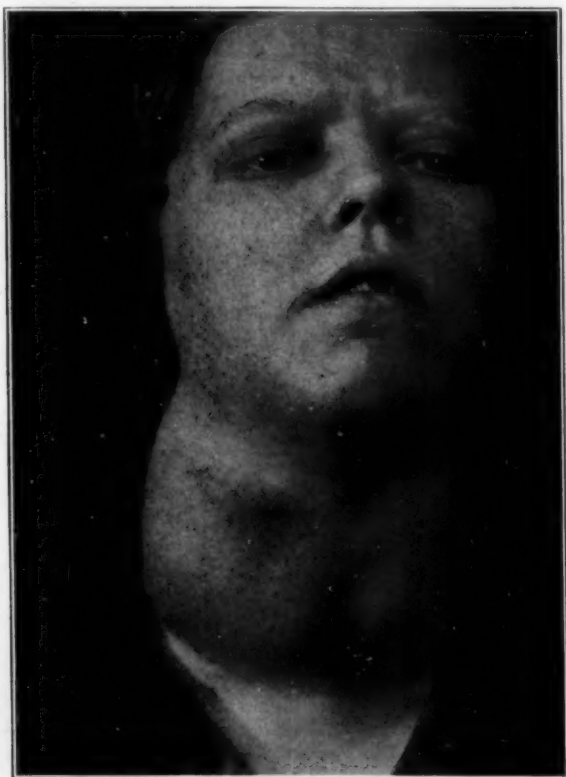


Fig. 2.—This young woman, aged 20, had had a rapid growing exophthalmic goiter for about a year. Besides the typical symptoms of the disease (basal metabolic rate +78), the goiter had produced marked tracheal compression with obstructive dyspnea. The presence of the severe hyperthyroidism, huge thyroid enlargement and the tracheal compression, is a clearcut indication for the employment of the stage-procedure (lobectomies) in the removal of the goiter.

present day mortality is derived from this group. As only slight benefit will be derived from any form of treatment other than resection of the part of the thyroid gland, these patients must be accepted for operation even at increased risk. Any modification of the operative procedure that would improve the patient's condition at a reduced risk should be sub-

stituted for primary subtotal thyroidectomy. This can be accomplished by resection of the gland in two stages. The operative risk of lobectomy is definitely less than that of subtotal thyroidectomy, for the surgical trauma and the chances of technical error attendant on the former are just half those of the latter. If the patient can endure lobectomy, the resulting improvement will be so marked that the second lobe can be resected later at a greatly diminished hazard. The occurrence of an accident at the second stage would not necessarily prove disastrous.



Fig. 3.—Fifteen months previously, the thyroid gland enlarged rapidly with symptoms of exophthalmic goiter and rapid loss of weight (40 pounds [18.1 Kg.]) and strength. On admission, the patient's basal metabolic rate was +80. Because of the presence of severe hyperthyroidism and the enormous thyroid enlargement, the right lobe and isthmus only were resected. After an interval of three months in which she improved markedly with a gain in weight of 42 pounds (19.1 Kg.) and a reduction of basal metabolism to +40, the left lobe was successfully resected.

Two other indications for dividing the resection into stages may be cited. The resection of both lobes in one stage, if the goiter is large and firm and definitely compresses the trachea, may remove the entire support of the walls of the trachea and result in sudden tracheal collapse. Resection of the goiter in two stages would prevent this. If the

patient is a poor risk or questionably poor and if at operation the resection of the first lobe is attended by certain technical complications, such as injury to the inferior laryngeal nerve, loss of much blood or the excessive prolongation of the operation, it is always advisable to postpone the resection of the second lobe.

If the two-stage procedure seems warranted, I believe that sufficient time, six weeks or more, should elapse between operations, so that the patient can gain strength before being subjected to the second stage; otherwise it may prove disastrous. If the second operation can be done safely within a few days, it is probable that the complete operation could have been performed with less risk in one stage.

SUMMARY

The employment of the multiple-stage operation as a means of reducing the mortality by combating the acute postoperative crises has been indispensable to the development of surgical treatment for exophthalmic goiter.

Standardization of the indications for the stage-operation was impossible, owing to the absence of any reliable criterion of the safety of subtotal thyroidectomy. Consequently, rather than endanger the patient, the stage-operation performed at less risk was used more extensively than was necessary.

The use of iodine in the medical preparation of patients with exophthalmic goiter has altered the need for the multiple operations. Whereas before the advent of iodine only 30 per cent of the patients with exophthalmic goiter were subjected to primary subtotal thyroidectomy and the other 70 per cent to from two to four preparatory procedures, the indications for the stage-operation have now been reduced to less than 2 per cent. Medical measures have supplanted operative procedures in the preparation of the patients for resection of the goiter, and the mortality has been reduced to 0.72 per cent.

There is a small group of late cases in which the goiter is large and firm, the basal metabolic rate high and evidence of visceral degeneration present in which the condition cannot be improved materially by any measure short of partial removal of the goiter. In this group, resection of the gland can be accomplished with less danger by removing one lobe at a time. Other indications for the stage-operation are cited.

PNEUMOCOCCIC PERITONITIS *

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Pneumococcic peritonitis differs essentially from peritoneal infections by other organisms. Because of these differences and because of its comparative rarity and high mortality rate, the disease presents points of the greatest clinical interest.

This paper, based on six cases, deals with (*a*) the incidence of the disease, (*b*) the types of infection, (*c*) the mode of infection, (*d*) the clinical manifestations of the different types, (*e*) the prognosis and (*f*) the treatment.

THE INCIDENCE OF THE DISEASE

It is impossible to give accurate figures as to the proportion of this type of infection, for it is probable that many cases in which bacteriologic studies are not made are overlooked or are recorded as streptococcic peritonitis.

McCartney and Frazer¹ stated that "about 2 per cent of the abdominal emergencies of childhood are due to abdominal pneumococcal infection." Jensen² found 106 cases in the literature before 1903. Beaven³ reported nine cases observed at the New York Babies Hospital between 1907 and 1920. These occurred in a series of 171 cases of general peritonitis, and the small number is probably due to the fact that in this hospital children over 4 years of age are not treated. Rischbeth,⁴ who reported fifty-seven cases from the London Hospital and the Hospital for Sick Children in 1910, believed that nearly one fourth of the cases of general peritonitis were pneumococcic. Lipshutz and Lowenburg,⁵ reporting twenty-three cases of pneumococcic and streptococcic peritonitis, stated that the two varieties constitute 10 per cent of the abdominal emergencies of childhood. In a review of 400 cases

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1. McCartney, J. E., and Frazer, John: Pneumococcal Peritonitis, *Brit. J. Surg.* **9**:479, 1922.

2. Jensen: *Arch. f. klin. Chir.* **70**:91, 1903.

3. Beaven, Paul W.: Pneumococcus Peritonitis in Infancy and Childhood, *Am. J. Dis. Child.* **20**:341 (Oct.) 1920.

4. Rischbeth, Harold: On Pneumococcal Peritonitis, *Quart. J. Med.* **4**:205, 1910-1911.

5. Lipshutz, Benjamin, and Lowenburg, Harry: Pneumococcic and Streptococcic Peritonitis, *J. A. M. A.* **86**:99 (Jan. 9) 1926.

of acute surgical diseases of the abdomen in children, Cohen⁶ found three instances of pneumococcic infection.

The six cases here recorded represent both the primary and the secondary form to pneumonia and pleurisy. One patient (case 1) was seen in private practice and five in the Emory University Division of the Grady Hospital; these cases were the only proved instances of this disease in about 30,000 admissions.

TYPES OF INFECTION

In 1901, Michaut⁷ divided pneumococcic peritonitis into primary and secondary varieties. Since that time most articles relating to it have followed that classification. Those cases in which the peritoneal infection is the first manifestation of the disease are classified as primary, and those in which the original focus was elsewhere than the peritoneum are classified as secondary. It is the belief of Rischbeth⁴ and Beaven,³ however, that all are secondary, and like pneumococcus infection in the lungs, or elsewhere, are dependent on one cause, namely, pneumococemia.

Annand and Bowen⁸ collected from the literature ninety-one cases which occurred in children below the age of 15. Thirty of these were secondary to a definite infection elsewhere in the body, forty-seven were primary, and in fourteen it was impossible to place the original focus.

McCartney and Frazer¹ suggested a further subdivision of the primary type—acute and chronic.

THE MODE OF INFECTION

In the cases of secondary peritonitis, the explanation of the disease is not difficult. Since most patients with pneumonia have an infection of the blood stream, it is probable, and altogether to be expected, that certain of them will develop peritonitis from embolic implantation of the pneumococci. Moreover, many patients with the secondary variety show the most marked evidence of the infection in the upper part of the abdomen and on the side adjacent to the affected lung. For this reason it may be supposed that the bacteria passed by direct extension through the diaphragm. If the bacteria are carried by the blood stream to the abdominal cavity, however, it is difficult to explain the rarity of the cases secondary to pneumonia, for certainly this is an infrequent complica-

6. Cohen, Morris: *Acute Surgical Diseases of the Abdomen in Children*, Surg. Gynec. Obst. **45**:595, 1927.

7. Michaut: *Thèse de Paris*, 1901; quoted by McCartney (footnote 14).

8. Annand, W. F., and Bowen, W. H.: *Pneumococcic Peritonitis in Children: A Study*, *Lancet* **1**:1591, 1906.

tion. Rolleston⁹ found only eleven instances in 4,454 cases of pneumonia, and Rischbeth⁴ only one in 6,000. The three cases here reported occurred in a series of 1,908 patients affected with pneumonia.

The experience of Peiser¹⁰ offered some explanation for the infrequency of the secondary invasion. He demonstrated that the peritoneum, so long as uninjured, was impermeable to organisms circulating in the blood stream, and invasion took place "only in the moribund stage of a severe septic process." Clinical observation supports this view, for the patients with secondary peritonitis practically always succumb. That infection passes through traumatized peritoneum is shown by the case of Leonardo¹¹ in which a fatal pneumococcus infection followed a blow on the abdomen.

The manner in which the peritoneum becomes primarily infected is more difficult to explain, and on this account the study of this type of case is more attractive. Numerous routes by which the infection may reach the abdominal cavity have been advocated. Among the theories suggested as to the origin of the infection are (1) the blood stream, (2) the gastro-intestinal tract, (3) the lymphatics and (4) the female genital tract.

Many observers, notably Koplik,¹² Michaut,⁷ Rischbeth,⁴ Montgomery¹³ and Beaven,³ expressed the belief that the peritoneum is infected through the blood stream, even though it is impossible to demonstrate an original focus of the invading bacteria.

As has already been mentioned, peritonitis is a rare complication of pneumonia. In a series of experiments, McCartney¹⁴ inoculated rabbits intravenously with pneumococci, but was unable to produce peritonitis; all the animals died within twenty-four hours from septicemia.

That the gastro-intestinal tract is the source of the infection was advocated by Stoos,¹⁵ Jensen,² Woolsey¹⁶ and others. In fact, Jensen² was able to produce one case of peritonitis by feeding pneumococci to guinea-pigs. However, McCartney¹⁴ was unable to produce the

9. Rolleston, H. D.: *Pneumococcic Peritonitis*, Clin. J. **31**:319, 1908.

10. Peiser: *Beitrag. z. klin. Chir.* **55**:484, 1907; quoted by Leonardo (footnote 11).

11. Leonardo, Richard A.: *Primary Pneumococcus Peritonitis*, Ann. Surg. **83**:411, 1926.

12. Koplik: *Diseases of Infancy and Childhood*, ed. 3, Philadelphia, Lea & Febiger, 1910, p. 572.

13. Montgomery, Albert H.: *Primary Pneumococcus Peritonitis in Children*, Surg. Gynec. Obst. **41**:798, 1925.

14. McCartney, J. E.: *The Pathogenesis of Primary Pneumococcal Peritonitis*, J. Path. & Bact. **26**:507, 1923.

15. Stoos: *Jahrb. f. Kinderh.* **56**:593, 1902.

16. Woolsey, George: *Pneumococcus Peritonitis*, Am. J. M. Sc. **140**:864, 1911.

disease in this manner. He was also unable to produce it in rabbits through the lymphatics of the vagina.

At the present time most observers believe that the primary variety of pneumococcic peritonitis is due to the passage of the bacteria through the fallopian tubes to the pelvis. This theory was first proposed by Brun¹⁷ in 1901, and was convincingly supported with clinical evidence by McCartney and Frazer¹ in 1922. Their conclusions were based on the fact that thirty-six of the fifty-six cases studied were primary and all occurred in young girls; whereas, twelve of the secondary type were in boys and eight in girls. They further stated that the disease begins in the pelvis and that only girls are affected. The latter statement has been refuted by Montgomery,¹³ who reported an instance of primary infection in a boy, and by Leonardo,¹¹ who collected from the literature five cases of primary infection in the male. Three primary cases in the male were reported by Annand and Bowen.⁸

In spite of these exceptions, the preponderance of clinical evidence is on the side of the genital theory of infection, and experimentally McCartney¹⁴ was only able to produce the disease in a monkey in this manner. It cannot be denied that instances of apparent primary infection occur in the male, as in case 5 of this series, but it is possible that these are really secondary to an undiscovered focus elsewhere in the body.

CLINICAL MANIFESTATION

The clinical manifestations of the disease are best illustrated by the following six cases. Of these, three followed pneumonia and three were apparently primary. The three patients with secondary infection died; necropsy was performed. Of the three primary cases, one patient died without operation and necropsy was done. The other two recovered following operation. In each the smear and culture of the peritoneal fluid showed pneumococci.

REPORT OF CASES

Secondary Pneumococcic Peritonitis.—CASE 1.—G. J., a colored girl, aged 5 months, entered Grady Hospital on Dec. 31, 1924. She was unconscious at the time she was admitted. The illness was of two days' duration and was characterized by refusal to nurse, rapid breathing and fever. The temperature ranged from 104 to 105 F.; the pulse rate from 140 to 160; the respirations from 60 to 80, and the white blood count was 18,000. There were signs of a bronchopneumonia on the right side, and the abdomen was rigid and distended. The condition grew rapidly worse, and the patient died forty-eight hours after admission. Necropsy showed bronchopneumonia in both lungs and a diffuse peritonitis without evidence of localization. A culture from the peritoneum gave a pure growth of pneumococci.

CASE 2.—L. R., a negro, aged 40, entered Grady Hospital on Dec. 22, 1924. His illness began six days previously with a chill and pain in the left side of the chest.

17. Brun: Presse méd. 9:93, 1901.

There were definite signs of lobar pneumonia of the left lung. The abdomen was distended and tender throughout. The temperature ranged from normal to 103 F.; the pulse rate from 100 to 130, and the respirations from 40 to 80. After the patient had been in the hospital for two days the abdomen became more distended, and he began to complain of abdominal pain. This increased until his death on December 27. Necropsy showed a lobar pneumonia of the left lung and a general peritonitis. Pneumococci in pure culture were grown from both lungs and the peritoneal fluid.

CASE 3.—M. B., a negress, aged 24, entered Grady Hospital on Feb. 7, 1925. She was seven months pregnant. Her illness began on February 2, with difficult breathing and high fever. Examination showed a lobar pneumonia of the right lung. Her condition gradually grew worse. A dead fetus was delivered on February 12. After this date she was unconscious. The abdomen became spastic and distended. The temperature ranged between normal and 103 F.; the pulse rate from 100 to 130, and the respirations from 30 to 40. The white blood count was 28,000 at the time she was admitted to the hospital and rose to 38,000 on the day of death, Feb. 19, 1925. Autopsy revealed a lobar pneumonia of the right lung and an early pneumococcic empyema of the right pleural cavity. The abdomen contained a large amount of thick yellow pus which extended throughout the cavity. A culture of this pus showed a pure growth of pneumococci.

Primary Pneumococcic Peritonitis.—CASE 4.—L. H., an unmarried negress, aged 20, entered the Grady Hospital on May 14, 1923. Three weeks before admission she became acutely ill with abdominal pain, distention and diarrhea. During this time she ran a high temperature, had an occasional chill and vomited once a day. The abdomen gradually became distended and was unrelieved by purgatives and enemas. At the time she was admitted to the hospital she was semiconscious. There was a slight jaundice in the conjunctiva. The chest and heart were normal. The abdomen was distended, tender and rigid throughout. There was dulness in the flanks which shifted with change of position, and a distinct fluid wave was present. The temperature ranged between 101 and 102 F. The pulse rate, which was weak, ranged between 100 and 130. The white blood count was 28,000. The diagnosis at the time of admission was tuberculous peritonitis, and paracentesis was done at this time. The fluid was cloudy and contained small flakes of fibrin. A smear and culture showed pneumococci in pure growth. The patient did not regain consciousness and died two days after admission. Necropsy did not show evidence of disease outside the abdominal cavity. The abdomen was filled with thin, cloudy, flocculent pus, which extended throughout the cavity, covering all the organs, without disposition to encapsulation.

CASE 5.—G. S., a negro, aged 29, entered Grady Hospital on Dec. 10, 1924. His illness began three days before admission with generalized abdominal pain which was severe and sudden in its onset. The initial pain subsided somewhat in the first twenty-four hours but returned with increased severity, particularly on the right side of the abdomen. On the second day, he was nauseated but did not vomit. His bowels moved four times without catharsis. He appeared prostrated and weak, with a temperature of 97 F. and a pulse rate of 88; the white blood count was 13,000. The abdomen was slightly distended, rigid and tender throughout, but the rigidity was more marked on the right side. A diagnosis of acute appendicitis was made and immediate operation carried out. The abdomen was opened through a right rectus incision. There was a considerable amount of free fluid, which was odorless and slightly flocculent. The intestines were red and distended. The appendix shared in the general intestinal inflammation but did not

appear to be the seat of the infection. It was removed and the abdomen closed without drainage. A culture of the abdominal fluid was not made. The patient reacted poorly, and three days later it was evident that he was suffering from a spreading peritonitis. The temperature had risen to 101 F. and the pulse rate to 140. The white cell count was 18,000. The abdomen became distended, tender and extremely rigid throughout. With the patient under local anesthesia, the abdomen was opened in the lower midline. There was a large amount of thin, blood-tinged, flocculent fluid. Exploration was not done, but it was apparent that the peritonitis was not walled off. Three drains were placed in the abdominal cavity. A culture and smear of the fluid showed pneumococci. Convalescence was stormy and prolonged. The patient was irrational, with a high fever and rapid pulse for three weeks. The character of the drainage changed from the thin serous type to a thick, greenish-yellow pus. The temperature and pulse gradually became normal, the discharge ceased, and he was able to leave the hospital seven weeks after entrance.

CASE 6.—M. H., a white girl, aged 8, entered St. Joseph's Infirmary on March 14, 1928. She had always been strong and healthy. Her illness began on February 24, eighteen days before entrance to the hospital, with abdominal pain, vomiting and high fever. The pain was described by her mother as being sudden in onset, extremely severe and prostrating. The vomiting was persistent for twenty-four hours, and during most of this time she was delirious. This condition continued for three days, at which time she was first seen by a physician. At that time she was delirious and restless, with a rise in temperature to 104 F. and a white blood count of 30,000. There was no evidence of infection in the throat, ears or lungs. The vomiting had ceased, but the abdomen was tender and slightly distended. There was a considerable number of pus cells in the urine, and a provisional diagnosis of pyelitis was made. The following day she was much improved, and her temperature had dropped to 102 F. For the next ten days she gradually improved and was able to get out of bed and take some of her meals at the table. The urine continued to show some pus cells, and the temperature ranged from 99 to 101 F. She continued to complain of slight abdominal pain.

On March 7, her mother noticed that her abdomen was distended and this increased up to the time of her entrance into the hospital. At that time (March 14, eighteen days after the onset of the illness), the abdomen was greatly distended, flat to percussion and with a definite fluid wave. The temperature was 100 F.; the white blood count 18,000. A diagnosis of tuberculous peritonitis was made, and paracentesis was done. The fluid was thick, greenish-yellow and contained many pneumococci. Operation was immediately performed under an anesthesia of procaine hydrochloride. A lower midline incision was made and 2,000 cc. of pus aspirated. The intestines were covered with a thick fibrinous exudate, as was the liver, which was greatly enlarged, the edge extending to the umbilicus. The intestines were agglutinated to the pelvic organs. The appendix was not examined. There was no evidence of walling off of the pus, which apparently extended throughout the abdomen. Four drains were placed in the cavity.

The patient showed immediate improvement, and three days after the operation the temperature reached normal. For two days nothing was given by mouth and fluids were administered subcutaneously. After this time she took liquids without difficulty, and the bowels moved with the aid of enemas. Profuse drainage from the abdomen ceased in three weeks, and the wound healed without difficulty.

Cultures of the pus showed the organism to be pneumococcus, type I, and the culture on different mediums was always slow to grow.

Vaginal smears and cultures from the vagina and throat failed to show pneumococci.

COMMENT

It is evident that the three cases of primary pneumococcic peritonitis present an entirely different clinical picture from that of the secondary type. The most striking thing is that two of the patients recovered with drainage, and one cannot but believe that had this procedure been done in case 4 the result might have been favorable.

Case 5, occurring in an adult male, bears out the contentions of Leonardo,¹¹ Annand and Bowen⁸ and others that the disease is not limited to girls, as is claimed by McCartney and Frazer.¹ Case 6 is of particular interest because of the recovery after such an extensive peritoneal involvement. This is probably accounted for by the fact that the type I organism is one against which a serum can be produced, and in that patient's case the body produced such an immunity. The three cases present the typical clinical features as pointed out by most authors who write on this subject. In each there was an abrupt onset of severe abdominal pain with rapid prostration, indicating an infection of great severity. Vomiting was early and violent, and the temperature, pulse and leukocyte count rose early. Diarrhea was frequent.

If the initial stage is not overwhelming, the patient gradually improves but does not fully recover, and the condition passes into a subacute stage, at which time a diagnosis of tuberculous peritonitis is usually made (cases 4 and 6).

The pathologic conditions are well illustrated by case 5. Here the first evidences were merely a reddening and congestion of the intestine with a thin exudate. Later this fluid became more profuse and contained flakes of fibrin, but did not become purulent until a week after the onset. McCartney and Frazer¹ pointed out this delay in leukocyte migration as an evidence of the intensity of the disease and viewed as unfavorable a delay in the appearance of pus.

The later pathologic conditions are well illustrated by cases 4 and 6. Here the initial storm was weathered, and the disease became more chronic. The migration of leukocytes caused the exudate to become definitely purulent, and the disease became less severe and more chronic.

PROGNOSIS AND TREATMENT

It would appear that the prognosis depends more on the severity of the infection and the individual susceptibility than on any type of treatment. The fatalities in the secondary cases coincide with the experience of other observers that recovery rarely occurs in this variety of case. Peritonitis, so often fatal in itself, has but little chance of a favorable outcome when combined with such a serious infection as pneumonia.

The experimental studies of David¹⁸ may throw some light on the prognosis and treatment of this type of infection. He found that "colon bacilli passed directly into the blood stream as well as into the lymphatics from the normal peritonum," and that lesser grades of peritonitis did not prevent passage of the bacilli into the lymphatics. However, a "well developed plastic peritonitis prevented the passage of bacillus coli from the peritoneum into the blood stream or into the lymphatics." From this it may be assumed that the patients who die early develop a septicemia from an overwhelming peritonitis; whereas in cases in which the disease is less acute, the infection is walled off by the protective mechanism of a plastic exudate, even though all the peritoneum is involved.

It would seem logical to base the treatment on this knowledge, that is, in the early stage to await the formation of a protective barrier. Operation at this stage of hyperpyrexia, cyanosis, rapid pulse and prostration would seem to be valueless, although McCartney and Frazer¹ advised early drainage and transfusion. When the exudate has become thick and purulent, drainage seems to be the only method whereby the infection may be overcome.

Observers are at variance as to the prognosis. Rischbeth⁴ found the total mortality in cases collected from London Hospitals to be approximately 90 per cent, as compared with 65 per cent in the series of McCartney and Frazer.¹ Many other writers are more pessimistic as to the outcome, believing that practically all cases terminate fatally. Annand and Bowen⁸ are more optimistic, having found recovery in forty-three of forty-six cases. Their figures would indicate that if the peritoneum is only locally involved recovery after drainage will usually take place, whether the disease is primary or secondary, but if there is diffuse peritoneal involvement, the prognosis is almost universally bad.

CONCLUSIONS

1. Pneumococcal peritonitis occurs infrequently as a secondary complication of pneumonia or as a primary infection.
2. The prognosis is poor, more than 50 per cent of cases reported ending fatally.
3. The primary variety occurs most frequently in young girls, but may occur in boys and men.
4. Drainage of the abdominal cavity is advocated; the two patients so treated recovered.

18. David, Vernon C.: Peritonitis: An Experimental Study, *Surg. Gynec. Obst.* 45:287, 1927.

THE OCCURRENCE OF *B. WELCHII* IN EXPERIMENTAL HIGH INTESTINAL OBSTRUCTION*

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The constant occurrence of *B. welchii* as an organism in the intestinal tract has been well established.¹ It has been equally well shown that the lower down the intestinal tract, the more prevalent is the organism.² In cases of intestinal obstruction in which enterostomy has been performed fairly high up, Williams³ has recovered the organism in both the intestinal drainage and the vomitus. In conjunction with the work of Morton and Stabins⁴ on "The Relation of the *B. welchii* Antitoxin to the Toxaemia of High Intestinal Obstruction," ample opportunity was afforded to investigate the occurrence of this organism at a certain level in the jejunum.

EXPERIMENTAL WORK

A simple intestinal obstruction was produced 10 inches (25.5 cm.) distal to the ligament of Treitz by section and inversion of both ends. Swabs were taken from the proximal loop for smear and culture. These are referred to as the first stage in the table. When the dogs appeared toxic clinically and the non-protein nitrogen had risen more than 40 mg. per hundred cubic centimeters, a lateral anastomosis was performed at the original site of obstruction, and at this time swabs were again taken from the proximal loop for smear and culture. These are referred to as the second stage in the table. For bacteriologic examination, smears were stained by the Gram method and cultures made by inoculating material on the swabs into two deep tubes of milk which

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1. Simonds, J. P.: Studies in *Bacillus Welchii*, with Special Reference to Classification and to Its Relation to Diarrhea, Rockefeller Inst. for Med. Res. Monograph no. 5, September, 1915. Berg, B. N.; Meleney, F. L., and Jobling, J. W.: Experimental Chronic Duodenal Obstruction, Arch. Surg. **14**:752 (March) 1927.

2. Cushing, Harvey, and Livingood, Louis E.: Experimental and Surgical Notes upon the Bacteriology of the Upper Portion of the Alimentary Canal, with Observations on the Establishment There of an Anaerobic State as a Preliminary to Operative Procedure on the Stomach and Small Intestine, Johns Hopkins Hosp. Rep. **9**:543, 1900. Torrey, J. C.: The Regulation of the Intestinal Flora of Dogs Through Diet, J. M. Research **39**:415, 1918-1919. van der Reis, V.: Die Bakterienflora des Dünndarms und des Coecums bei Erwachsenen unter normalen und pathologischen Verhältnissen, Klin. Wchnschr. **1**:950, 1922. Kahn, M. C.: Anaerobic Spore-Bearing Bacteria of the Human Intestine in Health and in Certain Diseases, J. Infect. Dis. **35**:423, 1924.

3. Williams, B. W.: The Importance of Toxaemia Due to Anaerobic Organisms in Intestinal Obstruction and Peritonitis, Brit. J. Surg. **14**:295, 1926-1927.

4. Morton, J. J., and Stabins, S. J.: To be published.

had been freshly boiled and cooled. One tube was heated at 80 C. for one hour to kill off the vegetative forms of the fecal flora. Both tubes were incubated at 37.5 C. The development of the "stormy fermentation" odor of butyric acid and smears from the culture indicated the presence of *B. welchii*.

RESULTS

In the normal jejunum at the level mentioned, the organism was isolated only four times in a series of twenty-four dogs. This does not mean that the organism could not have been isolated nor that it was not present in the animals. It does indicate, however, that it was present in exceedingly small numbers as compared with the second stage. Only eighteen of the twenty-four dogs were operated on secondarily,

Results of Cultures

Series No.	Bacillus welchii in			
	First Stage		Second Stage	
	Direct Smear	Culture	Direct Smear	Culture
1.....	Negative	Negative	Positive	Positive
2.....	Negative	Positive	Positive	Positive
3.....	Negative	Negative	Positive	Positive
4.....	Negative	Negative	Positive	Positive
5.....	Negative	Negative	Positive	Positive
6.....	Negative	Negative	Positive	Positive
7.....	Negative	Negative	Positive	Positive
8.....	Positive	Positive	Positive	Positive
9.....	Negative	Negative	Positive	Positive
10.....	Negative	Negative	Positive	Positive
11.....	Negative	Negative	Positive	Positive
12.....	Positive	Positive	Culture not taken	
13.....	Negative	Negative	Culture not taken	
14.....	Negative	Negative	Culture not taken	
15.....	Negative	Negative	Died, no culture	
16.....	Negative	Negative	Negative	Negative
17.....	Negative	Negative	Negative	Positive
18.....	Negative	Negative	Died, no culture	
19.....	Negative	Negative	Positive	Positive
20.....	Negative	Negative	Positive	Positive
21.....	Negative	Negative	Culture not taken	
22.....	Negative	Negative	Positive	Positive
23.....	Negative	Negative	Positive	Positive
24.....	Negative	Positive	Negative	Positive
Total positive.....	8%	17%	88%	94%

and in fifteen the organism was recovered in smear and in seventeen in culture. The percentage of positive cultures in the first stage was about 17 per cent and in the second stage about 94 per cent. The results of the cultures are summarized in the accompanying table.

SUMMARY AND CONCLUSION

B. welchii is a normal inhabitant of the intestinal tract. Experimentally, the organism has been recovered in 17 per cent of this series in the jejunum 10 inches distal to the ligament of Treitz. Under abnormal conditions produced by obstruction of the bowel at this level and while one is awaiting the development of toxic symptoms, the organism has been recovered in 94 per cent.

B. welchii multiplies rapidly in experimental high intestinal obstruction.

THIRTY-SEVENTH REPORT OF PROGRESS
IN ORTHOPEDIC SURGERY*

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MISCELLANEOUS

Investigation of End-Results in Treatment of Lesions of the Joint by Immediate Active Mobilization.—Willems⁴⁰ made an investigation of the present condition of some of the soldiers wounded during the war whom he had previously treated, with the view of determining the distant end-results of the treatment by immediate active mobilization in cases of injuries of the joint. He was able to examine eighteen patients, thirteen of whom had injuries of the knee joint and five of the elbow. The case histories were presented in detail, together with roentgenograms and photographs. In all of these cases, the result was excellent from the standpoint of function; muscles were well developed, the bony damage was well repaired, and the joint mobility was preserved. Exostoses at the margins of the joints were found in practically all the cases, whether infection was present or not, but they pointed away from the joint line and were so situated as not to interfere with motion. In the region of the elbow, the exostoses took the form of voluminous

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* This Report of Progress is based on a review of 203 articles selected from 409 titles dealing with orthopedic surgery appearing in medical literature between Feb. 25, 1928, and June 9, 1928. Only those papers that seem to represent progress have been selected for note and comment.

40. Willems, Charles: J. de Chir. **31**:1 (Jan.) 1928.

proliferation of the bone developing from the articular margins of all three bones and situated in the transverse plane. In none of the patients did the degree of disability exceed 15 per cent.

Blood Supply of Semilunar Cartilages.—An investigation of the blood supply of the semilunar cartilages and crucial ligaments was made by Pfab,⁴¹ who utilized material obtained from cadavers and amputated legs. By means of injections, he was able to show that the blood supply of the semilunar cartilages consists only of a network situated in the peripheral border and coming from the synovial membrane. The ends of the cartilages are but poorly supplied with blood. This explains why the prognosis for healing of a torn cartilage is so poor. The crucial ligaments have a better blood supply, particularly the posterior ligament and those parts of the ligaments which are closest to the bones. Conservative treatment of torn crucial ligaments may, therefore, be justified, although a certain amount of stretching of the structures may be expected to occur.

Cysts of Semilunar Cartilages.—Zadek and Jaffe⁴² reported the case of a young man with cysts of the internal semilunar cartilage. The symptoms had their onset several weeks after he had wrenched the knee. This is only the third case of cysts of the internal semilunar cartilage that has been reported.

The authors found the cysts to be true cysts lined with synovial-like endothelium. They believed that they were congenital. The case histories showed the presence of trauma in about half the reported cases, but it was regarded only as an initiating factor leading to a rapid filling of the preformed cysts with secretion.

Rôle of Alar Ligaments in Tears of Internal Semilunar Cartilage.—Bernstein⁴³ studied the knee joints of twenty fresh cadavers with the view of determining the mechanism of derangements of the semilunar cartilages. He came to the conclusion that the internal alar ligament sends fibers from the infrapatellar fat pad to the anterior cornu of the internal semilunar cartilage, and that with the knee slightly flexed, the foot abducted and the femur rotated inward, sudden contraction of the quadriceps may exert a pull on the alar ligaments which in turn displaces the cartilage forward, in which position it becomes pinched between the articulating surfaces of the knee.

"Bucket Handle" Fractures of the Semilunar Cartilages.—In a discussion on "bucket handle" fractures of the semilunar cartilages, Henderson⁴⁴ expressed the opinion that this is the most common type

41. Pfab: *Deutsche Ztschr. f. Chir.* **205**:258, 1928.

42. Zadek, I., and Jaffe, H. L.: *Cysts of Semilunar Cartilages of the Knee*, *Arch. Surg.* **15**:677 (Nov.) 1927.

43. Bernstein, V.: *Surg. Gynec. Obst.* **46**:554 (April) 1928.

44. Henderson, Melvin: *Bucket Handle Fractures of Semilunar Cartilages*, *J. A. M. A.* **90**:1356 (April 28) 1928.

of injury of the internal meniscus; he said that it is also occasionally encountered in injuries of the external semilunar cartilage. "Bucket handle" fractures were found in 70 of 232 operations for removal of semilunar cartilage that have been performed at the Mayo Clinic since 1910. Henderson believed that if the records were more accurate, the "bucket handle" type of injury would be found to have even a higher incidence. Of the 70 "bucket handle" fractures reported, 68 involved the internal and 2 the external meniscus. In the entire series studied, there were 214 injuries of the internal cartilage and 18 of the external, a proportion of about 12:1.

SURGICAL PROCEDURES ON THE TENDONS, BONES AND JOINTS

Interscapulothoracic Resection for Malignant Tumors in the Region of the Shoulder Joint.—Linberg⁴⁵ described his technic for interscapulothoracic resection for malignant tumors in the region of the shoulder joint and reported three cases in which the operation had been performed. In his conclusions he stated that "the interscapulothoracic resection of the shoulder is indicated in all malignant tumors of the shoulder girdle where infiltration of the vessel nerve bundle has not occurred. The saving of an arm enables the surgeon to persuade the patient to submit to this operation at an earlier stage, thus greatly improving the late results."

Results of Reconstructive Surgical Procedures on the Hand and Forearm.—Basing his remarks on a study of 250 patients who had undergone a total of 450 operations, Steindler⁴⁶ reported on the early and late results of reconstructive surgical procedures on the hand and forearm. The cases were discussed under two headings: operations for restoration of form and operations for restoration of function. Under the former heading, operative results were reported in the following conditions: flexion contracture of the wrist, pronation and supination contractures; contractures of the fingers and dermatogenetic contractures. Under the second heading, the following conditions were discussed: drop-wrist, drop-fingers, loss of the power of supination, impairment of finger flexion, thenar disability and injuries to the peripheral nerve.

[ED. NOTE.—Steindler's careful work on reconstructive surgical procedures on the upper extremity is well known, and his writings on the subject repay careful study. The outstanding characteristics of this article are the thorough preoperative study, the planning of the operations on mechanical and physiologic principles of normal function and the careful postoperative treatment.]

45. Linberg, Boris E.: *J. Bone & Joint Surg.* **10**:344 (April) 1928.

46. Steindler, A.: *Surg. Gynec. Obst.* **45**:476 (Oct.) 1927.

Arthrodesis.—For his presidential address to the Orthopaedic Section of the Royal Society of Medicine, London, in October, 1927, Bristow⁴⁷ chose as his subject, "Arthrodesis," for he considered the frequent resort to joint fusion one of the outstanding advances in treatment in the last decade. He reviewed the indications and contra-indications in various conditions and for various joints, the present position of arthrodesis in the treatment of tuberculosis of the joints and the different methods of obtaining fusion. He compared the relative advantages of arthrodesis and reconstructive operations in the treatment of painful hip joints.

[ED. NOTE.—This article does not add any new knowledge, but is valuable as showing the trend of opinion in England, influenced as it has been by recent American work. Bristow is progressive but cautious, and his opinions therefore merit respect.]

Horvath⁴⁸ discussed the position of optimum function for ankylosis of the shoulder and stated that in Spitzzy's clinic in Vienna the preferred position is one of 90 degrees abduction, 135 degrees forward position and moderate external rotation, the so-called "saluting position." Spitzzy considered arthrodesis the operation of choice in paralysis of the deltoid resulting from poliomyelitis.

[ED. NOTE.—We consider 90 degrees abduction excessive for ankylosis of the shoulder in most patients and prefer an angle of about 65 degrees. We have seen several patients with shoulders ankylosed at greater angles than this, who complained because of the inability to lower the arm to the side and of the ugly appearance which this occasioned when walking. This difficulty is more apt to arise in adults than in children, as the latter develop a greater range of scapular motion than the former.]

Transplantation of Gluteus Maximus for Paralyzed Gluteus Medius.—To correct the abductor limp from a weakened or paralyzed gluteus medius muscle, Telson⁴⁹ has transplanted the origin of the anterior half of the gluteus maximus muscle forward to a point on the iliac crest about 2 inches behind the anterior superior spine. Care is taken to preserve the blood and nerve supply. Following the operation, the hip is fixed in plaster for three weeks in a position of abduction, and at the end of this time exercises are started.

End-Results of Transference of the Crest of the Ilium for Flexion Contracture of the Hip.—Speed⁵⁰ reported the results of 100 operations for transference of the iliac crest in patients with flexion con-

47. Bristow, W. R.: *Brit. J. Surg.* **15**:401 (Jan.) 1928.

48. Horvath, B.: *Ztschr. f. orth. Chir.* **48**:355, 1927.

49. Telson, D. R.: *Surg. Gynec. Obst.* **46**:417 (March) 1928.

50. Speed, James: *J. Bone & Joint Surg.* **10**:202 (April) 1928.

tracture of the hip. In 85 per cent of the patients the condition resulted from infantile paralysis; the other 15 per cent were affected with spastic cerebral paralysis, infectious arthritis or tuberculosis. His conclusions were as follows:

The usual deformity in paralytic contractures of the hip is due to flexion and abduction. The abduction contracture must be corrected in the severer cases before full correction of the flexion can be obtained. Postoperative shock is usually due to tension on the soft structures about the hip which have not been sufficiently loosened. The more complete the operative procedure, the less the postoperative shock. The results from the above operation are satisfactory both in regard to the correction of the deformity and to its freedom from postoperative complications. The operation is indicated in cases where the flexion exceeds twenty degrees.

End-Results of Operative Formation of a Roof to the Acetabulum.—Spitzzy⁵¹ reported the end-results of an operation for the formation of an acetabular roof which he has performed in seven patients with irreducible dislocations of the hip. The method was described in 1923, and consists in exposing the hip (Hoffa's incision), replacing the head of the femur and then employing a graft from the tibia to form the roof. The graft, which is 5 cm. long and 2 cm. wide, is fixed firmly in a hole 1 cm. deep and 2 cm. wide formed just above the acetabulum. In the first case, the head was fixed in the acetabulum by pinning it with a thin bone peg. This peg was absorbed after a certain period. In another case, a long steel pin was used for this purpose, but in the later cases reliance was placed on the bone shelf from the start. Spitzzy reported the end-results as satisfactory in all of the patients treated. The graft became thicker and firmer in time and acted as a good roof.

[ED. NOTE.—We cannot see any technical or functional advantage in Spitzzy's method over the shelf operation as employed in this country.]

Stabilization of Flail Legs.—Gray⁵² advocated arthrodesis of the knee instead of the use of braces in children with flail knees following infantile paralysis. Arthrodesis could be ensured only by the use of a bone graft. The knee joint was exposed under a tourniquet and the condyles denuded of cartilage; then holes were drilled into the bared ends of the tibia and of the femur in a longitudinal direction, and a tibial graft was inserted. The graft was long enough to pass through both epiphyseal disks. In all six patients operated on over seven years ago, there was solid bony union. Two patients complained of massive edema of the legs, which in one disappeared after some years and in the other has persisted. One patient showed a subsequent genu valgum due to irregularity of growth at the epiphyseal disks, but in the other five patients interference with the rate or direction of growth was not observed.

51. Spitzzy, H.: Zentralbl. f. Chir. **55**:1282, 1928.

52. Gray, H. T.: Brit. J. Surg. **15**:390 (Jan.) 1928.

[ED. NOTE.—The question of arthrodesis of a flail knee in infantile paralysis is debatable. There is a considerable advantage in doing away with a brace, but in the opinion of most orthopedic surgeons this is more than counterbalanced by the sacrifice of the ability to flex the knee when sitting. Following fusion of the knee in children, there is considerable danger of the occurrence of a fracture or of the development of deformity of the leg. The part should be protected for a considerable period. We consider it dangerous practice to pass a bone graft through both epiphyseal disks on account of the risk of causing disturbance of bone growth.]

FRACTURES

Healing of Fractures.—Ely⁵³ reported an experimental study of the formation of internal callus. Using cats as the experimental animals, he drilled a hole 2.7 mm. in diameter through the cortex and into the medulla. He studied the process of repair in five cats at the end of thirteen, fourteen, thirty-four, forty-two and sixty-seven days. He found that the hole became filled with fibrous tissue continuous with the periosteum and often extending well down into the marrow canal. Instead of constituting a barrier to bony union, this formation of fibrous tissue was evidently a step in the healing process. In it, bony trabeculae formed irregularly. The author did not observe any necrosis of the cut margins of the cortex as described in many textbooks. Contrary to what he believed, bone was actually produced on the cut margin of the cortex. Cartilage was absent in the healing process.

By stripping the periosteum or removing it completely from the shaft of the bone, Ely⁵⁴ was able to delay union up to as much as thirty-five days in three of five cats. Autopsy on these three animals showed the formation of a false joint at the seat of fracture. The other two animals were killed on the seventy-sixth and one hundred and nineteenth days; the fractures were found united, the healing having been brought about, apparently, by the cortex.

[ED. NOTE.—Ely's observations on the delayed healing of fractures caused by extensive stripping of periosteum are in keeping with the clinical observation that open reduction often leads to delayed union in a shaft fracture when the operation has been accompanied by much damage to the periosteum.]

Relation of Parathyroids to Healing of Fractures.—By excision of three of the four parathyroids in cats, Ross⁵⁵ was able to delay healing

53. Ely, L. W.: Internal Callus: Experimental Study, Arch. Surg. **15**:936 (Dec.) 1927.

54. Ely, L. W.: The Healing of Fractures: An Experimental Study, Arch. Surg. **16**:942 (April) 1928.

55. Ross, D. E.: Relation of the Parathyroids to the Healing of a Fracture as Controlled by the Roentgen Rays, Arch. Surg. **16**:922 (April) 1928.

of experimentally produced fractures, from four to five weeks. During this time the blood calcium level was lowered from 2 to 3 cm. per hundred cubic centimeters of blood. At the end of this time it returned to normal, and callus formation began. Removal of only two parathyroids did not have any effect on the healing of the fracture.

Ross' work was mentioned in the department of "Current Comment" of *The Journal* of the American Medical Association,⁵⁶ and it was pointed out that while such studies prove a relationship between the parathyroids and the healing of fractures, a rational basis for parathyroid therapy is still lacking and must await the pursuit of further studies. The danger of hypocalcemia which is easily induced by overdosage with an active parathyroid preparation makes it imperative that clinical studies should be carefully controlled by accurate determinations of the serum calcium.

Damage to Bones and Reputations.—Under this striking title, Hey Groves⁵⁷ gave a summary of the histories of the last 100 patients seen by him for residual disability following fractures. Fractures of the knees were a notable exception, presumably because they were recognized as severe injuries and the patients were referred at once to a specialist instead of being treated by the attending physician. The fractures could be tabulated thus:

TABLE 3.—Data on Fractures by Hey Groves

Site	No. of Cases	Disability	How Avoidable
Humerus: upper end.....	4	Stiff shoulder	By splinting the shoulder joint in abduction
Humerus: shaft.....	3	Nonunion	By splinting the arm horizontally, and not vertically
Elbow: supracondylar.....	12	Stiff elbow	By avoiding forced movements
	3	Ischemia	By avoiding tight bandaging and full flexion of the elbow
Radius, ulna: shafts.....	17	Loss of rotation	By resorting to open operation and impaction of the radial fragments
Wrist (Colles).....	7	Malunion	By correct reduction
Femur, neck (transcervical)	9	Nonunion	(1) By impacting the fragments and (2) by holding them impacted, by the abduction plaster method or by open operation
Femur: shaft.....	12	Malunion, nonunion	By effective traction, preferably skeletal
Tibia, fibula: shafts.....	11	Malunion	By effective traction
	5	Nonunion	By avoiding plating
	5	Delayed union	Unknown
Ankle.....	11	Malunion	By correct reduction

Hey Groves' advice might be summed up thus: Make a roentgen examination of every injury. Secure good reduction. Prove that after reduction the alinement is satisfactory. Use simple traction, and in case of failure resort to open operation and impact the fragments. Do not

56. Current Comment, J. A. M. A. **90**:1714 (May 26) 1928.

57. Groves, E. W. Hey: *Lancet* **1**:167 (Jan. 28) 1928.

plate unless you can plate efficiently. Never plate an open fracture. Do not comment on another physician's treatment.

Injuries to the Nerves Complicating Fractures.—In a review on the causation and treatment of some of the more common injuries to the nerves in fractures, Billington⁵⁸ stated that the most common is an injury to the radial nerve. He found the matter of differentiating between simple contusion and severance of the nerve difficult and often impossible, and advised waiting to see whether a reaction of degeneration would appear, in which case, exploration was indicated. If the injury was merely a contusion, there would usually be evidence of returning function in several weeks. The signs to look for were: formication below the point of injury, shrinkage of areas of anesthesia from proximal to distal portions and return of deep sensibility of muscle tone and of muscle sense. He considered it a good rule to explore injured nerves in from two to three weeks after injury, if there was total motor and sensory paralysis and the reaction of degeneration had appeared. He emphasized the importance of proper splinting, both before and after the operation, and of physicaltherapy.

Open Reduction of Fractures.—Jackson and Cook⁵⁹ reviewed the records of 122 patients with fractures, who were treated by the open method. In three cases the wound became infected, and two of the patients died. These authors followed the Lane technic and employed Sherman plates and self-tapping transfixion screws. The fractures selected for open treatment were as follows: humerus, twenty-six; radius, five; radius and ulna, sixteen; ulna, eleven; femur, twenty-six; tibia, five; tibia and fibula, sixteen; clavicle, ten, and patella, seven.

They concluded that open reduction with proper armamentarium and technic is no more dangerous than ordinary laparotomy; it is less painful. There is more certainty of the patient returning to his former occupation, and he returns sooner than when the closed method is used. There is less likelihood of the development of extensive callus, pain and disability. It is easier to obtain correct approximation and better function. It favors the institution of early massage and motion.

[ED. NOTE.—A mortality of 1.6 per cent from infection following operation does not permit one to argue that the open method is as safe as the closed method of treatment.]

Fracture of Odontoid Process.—Osgood and Lund⁶⁰ reviewed the subject of fracture of the odontoid process and reported one case, the

58. Billington, R. W.: *South. M. J.* **21**:91 (Feb.) 1928.

59. Jackson, J. A., and Cook, C. K.: *Am. J. Surg.* **4**:57 (Jan.) 1928.

60. Osgood, R. B., and Lund, C. C.: *New England J. Med.* **198**:67 (March 1) 1928.

fracture having been sustained by one of the writers. They pointed out that the lesion is less rare than usually thought, and that contrary to the usual opinion, many of the patients do not die; the saving feature is the large size of the spinal canal of the atlas, which is larger than that of any of the other vertebra. To demonstrate the fracture by roentgen examination, the rays must be directed through the wide open mouth. The fracture is characterized by slow healing and long continued protection is necessary. The treatment in the case reported consisted of rest in bed and the use of a cardboard Thomas collar for two weeks, during which time dysphagia disappeared and pain diminished. A large steel reinforced leather cuirass fixing the head and dorsal spine was then applied and worn for three months. This was followed by the use of a leather Thomas collar for three months more. Function was completely reestablished at the end of six months.

Fracture of the Transverse Processes.—Refuting the general impression that fracture of the transverse processes is an uncommon injury, Magnus⁶¹ cited the fact that he was able to collect ninety-nine cases of isolated fractures of one or both transverse processes among the patients admitted to his hospital during the years 1926 and 1927 alone. In forty-four patients, only one transverse process was fractured; in eight, the transverse processes of the second, third and fourth lumbar vertebrae were fractured on both sides; in the remaining forty-seven, two or more processes were affected.

There was much variation in the direction of the fracture lines and the degree of displacement. The author was of the opinion that isolated fracture of the transverse process is always caused by indirect violence. The transverse process is too deeply situated and too well protected to be exposed to direct violence; moreover, in none of the cases studied was there an accompanying fracture of the spinous process as would be expected if direct trauma was responsible. While the anatomic results were not always good, the functional results were excellent in all of the patients who had been treated adequately; that is, by prolonged rest in bed, employing a plaster shell, followed by the use of supporting apparatus during the convalescent stage.

Fracture of the Neck of a Rib by Indirect Violence.—Branson and Brailsford⁶² reported an instance of fracture of the neck of the tenth rib from indirect violence. A man, aged 60, was driving a golf ball when he suddenly experienced severe lumbar pain on the left side. The authors cited two published reports of fractures of the bodies of the rib by muscular action.

61. Magnus: Zentralbl. f. Chir. 55:1354, 1928.

62. Branson, G., and Brailsford, J. F.: Brit. M. J. 1:346 (March 3) 1928.

Fractures of the Clavicle.—Conwell⁶³ published end-result studies in ninety-two cases of fracture of the clavicle. He employed an adhesive plaster dressing intended to pull the shoulder backward, outward and upward, and considered that it had advantages, in respect to both comfort and efficiency, over other ambulatory dressings. He doubted if any method of splinting had yet been perfected which secured complete reposition of the fragments. In the cases studied, he reported the final position good in fifty patients, fair in thirty-seven and poor in fifteen. The functional end-results were, however, much better, being reported as excellent in seventy-five, fair in twelve and poor in five.

Local Anesthesia in Reduction of Fractures of Forearm.—Rice⁶⁴ has used local anesthesia with gratifying results for the reduction of fractures of the lower end of the forearm, injecting from 15 to 60 cc. of procaine hydrochloride directly into the seat of fracture. In a series of more than fifty cases, satisfactory anesthesia was obtained, in all except two. The two exceptions were cases in which the method had been employed successfully the day before, but in which, because satisfactory position had not been obtained, it had been necessary to perform a second manipulation. The writer felt that the failure was due, not so much to lack of anesthesia of the fragments, as to the inability to overcome the tenderness and soreness throughout the muscles of the forearm.

[ED. NOTE.—Some of the editors have had experience with the use of local anesthesia in the reduction of wrist fractures and consider the method ideal in certain cases, particularly for elderly patients for whom general anesthesia is contraindicated.]

Bone Graft for Ununited Fracture of the Carpal Scaphoid.—Adams and Leonard⁶⁵ treated a patient with an ununited fracture of the carpal scaphoid by an operation for bone grafting. The edges of the fracture were freshened and a small cortical inlay graft was placed across the fracture line. The result was successful, solid bony union being obtained in less than a year. The patient, a pugilist, recovered nearly perfect function and was able to return to his calling.

[ED. NOTE.—The report of one case, even though successful, is not enough to prove the point, but in this instance the method is original and suggests a way to approach a problem for which there has hitherto been no satisfactory solution.]

63. Conwell, H. E.: Fractures of the Clavicle: Simple Fixation Dressing with Summary of Treatment and Results Attained in Ninety-Two Cases, *J. A. M. A.* **90**:838 (March 17) 1928.

64. Rice, Carl O.: Local Anesthesia in Reduction of Fractures of the Forearm, *J. A. M. A.* **90**:1769 (June 2) 1928.

65. Adams, J. D., and Leonard, R. D.: *New England J. Med.* **198**:401 (April 12) 1928.

Central Dislocation Fractures of the Acetabulum.—Fifteen cases of central dislocation fractures of the acetabulum were collected and studied by Eliason and Wright.⁶⁶ The authors believed that this injury is increasing as a result of automobile accidents. For treatment they advocated manipulative reduction by flexion, wide abduction and slight external rotation, followed by immobilization in a plaster spica in the same position. They found associated pelvic fractures in over 50 per cent of the patients; pelvic and abdominal complications were of frequent occurrence and injuries of the nerve were present in 33 per cent.

[ED. NOTE.—While manipulative reduction as described by the authors allows correction of the deformity in certain of these dislocation fractures, there are others in which this method is unsuccessful. For these patients we would advocate the method of two way skeletal traction described by Putti.]

Fractures of the Tibial Tuberosities.—Moreau⁶⁷ studied twenty-two patients with fractures of the tibial tuberosities, the figures including sixteen closed fractures and six open fractures resulting from shell wounds, the general characteristics of which did not differ materially from the closed fractures. The lesions were classified as follows: (1) fractures of external tuberosity, thirteen; (2) fractures of internal tuberosity, four; (3) fractures of both tuberosities, five. All of the patients were treated without operation; aspiration was performed on the knee, which was then immobilized by the application of a plaster casing. The results, according to the author, were as good as could be desired, and in his opinion demonstrated that operative fixation was unnecessary.

[ED. NOTE.—Joint fractures must be regarded not only from the point of view of immediate functional results, but also from the point of view of distant future results. We know that a joint may appear hopelessly damaged and crippled fifteen years after an injury by reason of osteo-arthritic and degenerative changes resulting from the constant and long continued irritation of motion between incongruous joint surfaces when the functional result might have appeared perfect after from two to three years. If more perfect reconstitution of the joint surfaces can be obtained by operation than by closed methods of treatment, we would consider the operation justified because these later joint changes would be minimized. It does not appear to us that Moreau has taken this matter into consideration in reaching his conclusions.]

66. Eliason, E. L., and Wright, V. W.: *Surg. Gynec. Obst.* **46**:509 (April) 1928.

67. Moreau, Laurent: *Rev. d'orthop. et de chir.* **15**:193 (May) 1928.

Skeletal Traction in Compound Fractures of the Bones of the Leg.—Conwell⁶⁸ treated 50 of a series of 125 compound fractures of the bones of the leg by skeletal traction with Steinman's pin passed through the os calcis. These were the more severe injuries. The results were most satisfactory, and ill effects did not result from the use of the pin.

DISLOCATIONS

Fascial Repair of Acromioclavicular Joint Following Dislocation.—Fascial repair is used to prevent upward displacement of the outer end of the clavicle after dislocation of the acromioclavicular joint with rupture of the ligamentous attachments of the outer end of the clavicle. Bunnell⁶⁹ performed an operative repair, employing a 10 inch strip of fascia lata as the suture material. The fascia was passed downward through a drill hole in the tip of the acromion, slightly in front of the center of the joint, upward through a drill hole in the outer end of the clavicle, then downward and around the coracoid process and finally upward through the clavicle at the level of the outer end of the trapezoid ligament. The two free ends of the fascia were then sutured together with heavy silk. The result is stated to have been excellent.

Carrell⁷⁰ likewise employed fascial suture in two patients with acromioclavicular dislocation, and reported good results. He used a fascial strip one-half inch (1.27 cm.) wide and 4½ (11.4 cm.) inches long, passed it through two drill holes in the clavicle and then wove it through the base of the coraco-acromial ligament. He made a separate repair of the acromioclavicular ligaments, using fascia or chromic catgut.

[ED. NOTE:—Both of these methods are anatomically correct in that they recognize the importance of the coracoclavicular ligaments in retaining the clavicle in position and attempt to repair the damage to these structures.]

AMPUTATIONS

End-Results of Major Amputations.—Kuhn and Wilson⁷¹ reviewed 420 major amputations performed at the Massachusetts General Hospital and investigated the end-results. These operations comprised the entire number of major amputations performed during the ten year period, 1916-1926, and constituted 1 per cent of all operations. The authors concluded that drainage is practically never indicated in clean amputation stumps, and that the use of drains frequently leads to the formation of persistent sinuses.

68. Conwell, H. E.: *J. Bone & Joint Surg.* **10**:268 (April) 1928.

69. Bunnell, S.: *Surg. Gynec. Obst.* **46**:563 (April) 1928.

70. Carrell, W. B.: *J. Bone & Joint Surg.* **10**:314 (April) 1928.

71. Kuhn, J., quoted by Geschickter, C. F., and Copeland, M. M.: *Multiple Myeloma*, *Arch. Surg.* **16**:807 (April) 1928. Wilson, P. D., *ibid.*

The Gritti-Stokes amputation gave better functional results than did amputations higher in the thigh. In amputations below the knee, they found the appliances usually well tolerated. Symes' amputation gave good results in five of six cases.

The importance of the use of temporary appliances in amputations of the lower extremity was emphasized by the results, which showed a marked reduction of disability time in those cases in which such appliances had been used.

Only six of thirty-four patients treated by amputations of the upper extremity who were followed for several years made use of prostheses.

In thrombo-angiitis obliterans and allied diseases, multiple amputations were found to have been necessary in most instances. The authors pointed out the importance of conservative measures and of attempts to improve the circulation both before and after amputation.

The end-results in the group of patients on whom amputation had been performed for tuberculous joint disease showed a mortality of 50 per cent. This was largely due to failure to follow the operation by antituberculous measures and general constitutional treatment.

In arteriosclerotic gangrene, the Gritti-Stokes amputation gave the best results.

Eight of twenty-eight patients with sarcoma who had undergone amputation were surviving several years after amputation.

RESEARCH

Growth of Long Bones.—Gatewood and Mullen⁷² published the results of an experimental study of the growth of long bones. The experiments were carried out on rabbits. Markers in the form of shot were inlaid in drill-holes in the cortex of the femoral shaft 1 cm. apart. Roentgenograms were taken at intervals up to eighty-four days after operation. There was no separation of the shot.

In two series of experiments, attempts were made to close the epiphyses by removal of periosteum and by drilling holes into the epiphyseal cartilage plates on the side nearest the joint.

The authors concluded that longitudinal growth does not occur in the diaphyses of long bones, except at the epiphyseal cartilage plates, either under normal conditions or when an increased functional demand is made by closing or by hastening the closure of the epiphyses.

72. Gatewood and Mullen, B. P.: Experimental Observations on Growth of the Long Bones, *Arch. Surg.* 15:215 (Aug.) 1927.

Deposition of Lipoids Within the Tendons.—Kusnetzowski⁷³ conducted a series of experiments on rabbits, feeding them large doses of cholesterin, without being able to demonstrate the deposition of lipoids of any amount within the substance of tendons. If, however, he produced local damage to the tendons simultaneously with the large ingestion of cholesterin or if he introduced a foreign body, a considerable quantity of lipoids were found within the tendon. The macrophages of the granulation tissue were changed into conglomerations of xanthoma cells. The author pointed out that in patients with hypercholesterinemia following traumatism, distinct deposits of lipoids were observed within the tendons.

73. Kusnetzowski: *Virchows Arch. f. path. Anat.* **263**:205, 1927.

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